This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

Stanford University Libraries
3 6105 006 939 677

LELAND STANFORD JR.
UNIVERSITY
·LIBRARY·

THE GIFT OF

[illegible]

[illegible]

BULLETIN

OF THE

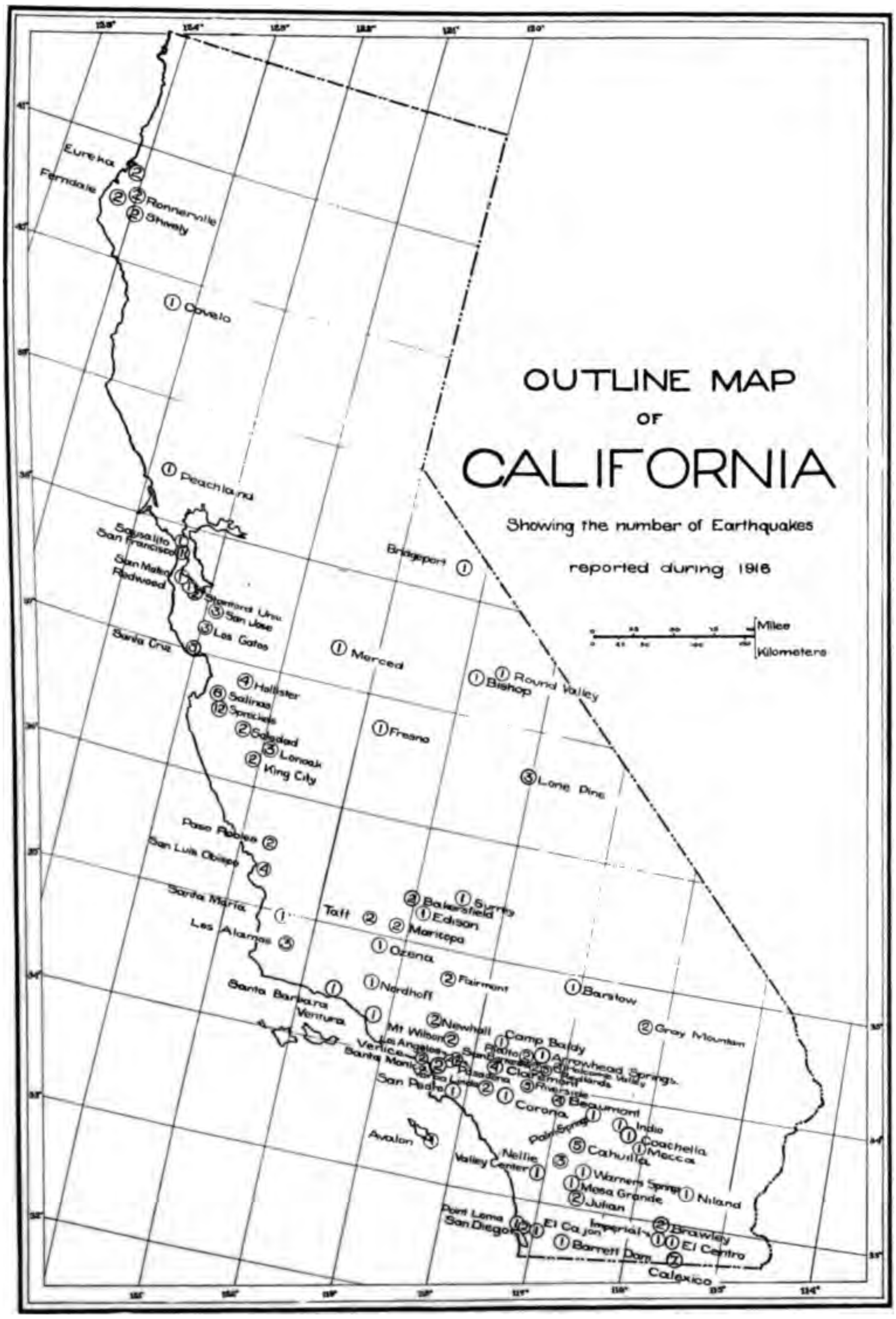
SEISMOLOGICAL SOCIETY OF AMERICA

VOLUME VII
1917

STANFORD LIBRARY

STANFORD UNIVERSITY, CALIFORNIA
PRINTED FOR THE SOCIETY
1917

300474



OUTLINE MAP OF CALIFORNIA

Showing the number of Earthquakes reported during 1916

The Bulletin of the
Seismological Society of America

VOL. VII MARCH 1917 No. 1

CALIFORNIA EARTHQUAKES DURING 1916

By ANDREW H. PALMER, Observer, U. S. Weather Bureau

Seismological work has been conducted by the United States Weather Bureau since July 1, 1914. In California the work has thus far been concerned chiefly with sensible earthquakes,—those having an intensity of II or higher in the Rossi-Forel scale. These earthquakes alone form the basis of this discussion.

The seismological work of the Weather Bureau in California, in so far as it refers to sensible earthquakes reported by cooperative observers, is being carried on through the section center at San Francisco. The following report is based on the cooperation of a total of 326 seismological stations, consisting of 12 regular or first-class Weather Bureau stations, and 314 stations where the observers, most of whom also serve as climatological observers, have volunteered to aid in the reporting of earthquakes. These seismological observers have been provided with printed instructions, together with cards for reporting earthquakes. As it is recognized that psychological factors play an important part in the recording of sensible earthquakes, the character of the observers deserves special consideration. Except at the regular Weather Bureau stations, nearly all of these observers render both climatological and seismological reports without compensation, and this fact alone indicates their interest in and capacity for the work. Actuated largely by public spirit, these observers are almost without exception leading citizens in the various communities which they represent. Furthermore, the care required in the daily meteorological observations is a form of discipline which soon makes one exercise good judgment in the recording of natural phenomena. With more than 300 observers of this caliber generally distributed throughout California, and all on the alert for detecting earthquake shocks and their attendant phenomena, it is believed that few, if any, sensible earthquakes have occurred during 1916 which have passed unreported.

The Occurrence of Earthquakes During 1916

During 1916 a total of 66 earthquakes sufficiently strong to be felt by persons occurred in 81 different places in California. During the preceding year 83 earthquakes were reported. The decline in the number of shocks was doubtless real, for there were 135 more observers in 1916 than during the preceding year, and, moreover, these had been secured as the result of a special effort made to increase the number of observers in regions like the Imperial Valley which had shown marked seismicity during 1915.

The monthly distribution and the total annual number of earthquakes and the reports received were as follows:

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Year
Earthquakes	4	5	2	1	6	4	6	12	8	6	6	6	66
Reports received	6	7	2	1	9	10	25	33	26	43	6	6	174

During the dry half-year, May to October inclusive, 42, or 64 per cent of the total number of earthquakes, occurred, while during the wet half-year, November to April inclusive, the remaining 24, or 36 per cent of the total, were recorded. During the preceding year the earthquakes were about equally divided between the wet and the dry seasons.

Of the 66 earthquakes which occurred during 1916, 43, or 65 per cent, were felt at one station only: that is, they were of such limited extent that they were not felt at two or more adjacent stations. These shocks were of relatively feeble intensity, and usually were of brief duration. Though it may be only a singular coincidence, it is worthy of remark that the proportion of the total number of shocks felt at one station only was exactly the same in 1915 and 1916.

During the past year California experienced more earthquakes than all the rest of the United States. Though it contains but 5 per cent of the area of the whole country, it had more earthquakes than the remaining 95 per cent of the area. The same condition prevailed during 1915.

Table I is a summary of all the California earthquake reports received during the year. The time of occurrence is the approximate Pacific, or 120th meridian time, and the hours are numbered from 0 to 23 inclusive. Great accuracy of time is not assumed, as the time

TABLE I. NON-INSTRUMENTAL EARTHQUAKE REPORTS, CALIFORNIA, 1916.

Day	Approx. time 120th Mer.	Station	Approx. Lat. (N.)	Approx. Long. (W.)	Intensity R-F	Number of Shocks	Duration Sec.	Sounds	Remarks
Jan. 1	15 55	Claremont	34°07′	117°44′		1		None	
1	15 55	Corona	33 52	117 35	3	1	¼	Rumbling	
1	15 55	Rialto	34 12	117 27	3	2	1	None	Rattled windows and doors
10	21 15	Cahuilla	33 32	116 43	4	1	10	Rumbling	Rattled windows
15	1 55	Calexico	32 40	115 28	4	2		None	People awakened
15	16 41	Peachland	38 24	122 50	2	1	4	None	
Feb. 1	22 30	Julian	33 05	116 37	2	1	4	Rumbling	
4	12 30	Hollister	36 50	121 20	5	1		None	
4	12 30	Spreckels	36 20	121 48	3	1		None	
19	7 05	Bridgeport	38 18	119 15	3	2	40	None	
25	15 30	Cahuilla	33 32	116 43	4	1		Rumbling	Shook buildings
25	15 30	Nellie	33 22	116 52	3	1		None	
27	5 26	Los Alamos	34 45	120 15		1		None	
Mar. 1	11 15	Los Alamos	34 45	120 15		1		None	
11	19 15	Imperial	32 50	115 35	4	1	2	None	
Apr. 12	20 23	Lone Pine	36 37	118 01	4	3	10	Rumbling	Doors rattled
May 2	6 28	Camp Baldy	34 15	117 40		1		None	
2	6 28	Claremont	34 07	117 44	4	2	1	None	
2	6 28	Los Angeles	34 03	118 15	3	1	5	None	
2	16 30	Salinas	36 36	122 40		1		None	
2	16 30	Spreckels	36 20	121 48		1		None	
5		Spreckels	36 20	121 48		1		None	
14		Spreckels	36 20	121 48		1		None	
24	20 23	Brawley	32 59	115 40		1		None	
27	9 00	San Diego	32 43	117 10	2	1		None	
June 7	14 15	Calexico	32 40	115 28	3	1	2	Rumbling	
26	5 46	San Luis Obispo	35 18	120 39	2	1	2	None	
27	5 45	King City	36 13	121 06	3	1		None	
27	5 45	Lonoak	36 16	120 58	4	1		None	
27	5 45	Salinas	36 36	122 40		1		None	
27	5 45	Santa Cruz	36 56	122 02	3	1	5	None	
27	6 15	Paso Robles	35 34	120 40		1	2	None	
27	6 15	San Jose	37 20	121 54	3	1	5	None	
27	6 15	Santa Cruz	36 56	122 02	2	1	2	None	
27	6 15	Spreckels	36 20	121 48		1		None	
July 1	6 15	San Jose	37 20	121 54	3	1	6	None	
4	20 41	Eureka	40 48	124 11	5	3	1	None	
4	20 41	Ferndale	40 34	124 15	6	1	few	Roaring	
4	20 41	Rohnerville	40 33	124 11		1		None	
4	20 41	Shively	40 25	123 56		1	7	None	
6	11 20	San Jose	37 20	121 54	4	1	2	None	
16	3 50	Beaumont	33 55	117 00	5	1	4	None	

Day	Approx. time 120th Mer.	Station	Approx. Lat. (N.)	Approx. Long. (W.)	Intensity R-F	Number of Shocks	Duration Sec.	Sounds	Remarks
July 16	3 50	Holcomb Valley	34 17	117 05	2	1	2	None	
16	3 50	Los Angeles	34 03	118 15	2	1	3	None	
16	3 50	Mount Wilson	34 13	118 16	2	1		None	
16	3 50	Nellie	33 22	116 52		2	1	None	
16	3 50	Redlands	34 04	117 12	4	2	3	Rumbling	
16	3 50	Rialto	34 12	117 27	2	1	1	None	
16	3 50	Riverside	33 58	117 21	2	1		None	
16	3 50	San Bernardino	34 06	117 17	4	1		None	
16	3 50	Seven Oaks	34 05	117 12		1	4	None	
16	4 30	Barstow	34 53	117 12	5	2	3	None	
16	4 30	Beaumont	33 55	117 00	5	1	2	None	
16	4 30	Holcomb Valley	34 17	117 05	3	1	2	None	
16	4 30	Redlands	34 04	117 12		1		None	
16	4 30	Riverside	33 58	117 21	2	1		None	
16	4 30	San Bernardino	34 06	117 17	4	2	15	None	
16	4 30	Seven Oaks	34 05	117 12	2	1	3	None	
27	22 12	Redlands	34 04	117 12	2	1	2	None	
27	22 12	Riverside	33 58	117 21	2	1		None	
Aug. 1	16 44	Covelo	39 47	123 16	3	1	2	Rumbling	
6	11 40	Hollister	36 50	121 20	5	1	15	None	Rocked buildings
6	11 40	Lonoak	36 20	120 55	4	1		None	
6	11 40	Los Gatos	37 12	121 58	3	1	5	Faint	
6	11 40	Merced	37 21	120 27	4	1	5	None	Doors moved
6	11 40	Paso Robles	35 34	120 40	3	1	1	Rumbling	Houses trembled
6	11 40	Redwood City	37 28	122 13	3	1	4	None	Windows rattled
6	11 40	San Francisco	37 48	122 26	2	1	2	None	
6	11 40	San Mateo	37 33	122 21	3	1	4	None	Buildings trembled
6	11 40	Santa Cruz	36 57	122 02	4	1	8	None	
6	11 40	Sausalito	37 50	122 29	3	1	4	None	Rocking movement
6	11 40	Soledad	36 25	121 18		1		None	
6	11 40	Spreckels	36 35	121 38	5	2		None	
6	11 40	Stanford Univ.	37 27	122 12	3	1	4	None	
6	12 55	Hollister	36 50	121 20		1		None	
6	12 55	Salinas	36 40	121 28	3	1		None	
6	12 55	Spreckels	36 35	121 38	5	1		None	
7	8 15	Salinas	36 40	121 38	3	1		None	
8	2 45	Salinas	36 40	121 38	3	1		None	
8	3 00	Salinas	36 40	121 38	4	1		None	
8	8 50	Los Gatos	37 12	121 58	4	1	10	None	
8	8 50	Santa Cruz	36 57	122 02	5	1	5	None	Felt by everyone
8	8 50	Soledad	36 25	121 18		1		None	
8	8 50	Spreckels	36 35	121 38	4	1		None	
8	8 50	Stanford Univ.	37 27	122 12	3	1	4	None	
13	23 20	Lone Pine	36 37	118 01		2		Rumbling	

Day	Approx. time 120th Mer.	Station	Approx. Lat. (N.)	Approx. Long. (W.)	Intensity R-F	Number of Shocks	Duration Sec.	Sounds	Remarks
Aug20	21 00	Yorba Linda	33 51	117 50	3	1		None	
21	3 00	Yorba Linda	33 51	117 50	3	1		None	
23	6 55	Eureka	40 48	124 11	5	2	30	Rumbling	Caused some alarm
23	6 55	Ferndale	40 34	124 15			2	None	
23	6 55	Rohnerville	40 33	124 11	4	3		None	
23	6 55	Shiveley	40 25	123 56	5	1	1	None	
31	16 30	Spreckels	36 35	121 38		1	1	None	
Sept. 1	4 20	Holcomb Valley	34 17	117 05	3	1	1	None	
1	23 00	Holcomb Valley	34 17	117 05	4	3	3	None	
6	11 40	Spreckels	36 35	121 38		3	3	Rattling	
8	8 50	Spreckels	36 35	121 38		1		None	
27	19 45	Hollister	36 50	121 20		1		None	
29	4 20	Calexico	32 39	115 29	3	1		None	
29	18 11	Arrowhead Sps.	34 15	117 16	2	1	1	None	
29	18 11	Barrett Dam	32 40	116 40	3	1		None	
29	18 11	Beaumont	33 55	117 00	4	1	3	None	
29	18 11	Cahuilla	33 32	116 43	4	2	20	Rumbling	Shook buildings
29	18 11	Coachella	33 40	116 10	5	2	30	Rumbling	
29	18 11	El Cajon	32 48	116 58	4	1	30	Rumbling	
29	18 11	Julian	33 05	116 37	5	1	15	Rumbling	
29	18 11	Mecca	33 34	116 05	4	1		None	Shook houses
29	18 11	Mesa Grande	33 11	116 42	4	1	5	Rattling	
29	18 11	Nellie	33 22	116 52	4-5	1		None	
29	18 11	Palm Springs	33 49	116 37	5	1	60	Rumbling	
29	18 11	Point Loma	32 43	117 15	3-4	1	3	None	
29	18 11	Redlands	34 04	117 12	2	1		Faint	
29	18 11	Riverside	33 58	117 21	3	2	2	None	
29	18 11	San Diego	32 43	117 10	2	1	3	None	
29	18 11	Valley Center	33 13	117 03	5	1		Rumbling	
29	18 11	Warner Spgs.	33 17	116 37	4	1	15	Rumbling	
29	20 25	El Centro	32 50	115 32	4	1	50	None	Dishes rattled
29	20 25	Indio	33 43	116 12	4-5	1		None	
29	20 25	Niland	33 16	115 31		1		None	
Oct. 8	20 50	Round Valley	37 24	118 37	3	3	5	Rumbling	
19	3 30	Cahuilla	33 32	116 43	2	1	5	Rumbling	
22	18 44	Bakersfield	35 22	119 00	5	4	6	Rattling	
22	18 44	Claremont	34 06	117 42		1	10	None	
22	18 44	Edison	35 21	118 53	3	3	20	None	Dishes rattled
22	18 44	Fairmont	34 45	118 25	4	1		Rumbling	
22	18 44	Fresno	36 43	119 49	3	1	5	None	
22	18 44	Gray Mountain	34 38	116 15	3	3	15	None	
22	18 44	Los Angeles	34 03	118 15	4	1	5	None	
22	18 44	Maricopa	35 05	119 08	4	2	9	None	
22	18 44	Mount Wilson	34 13	118 03	2	2	4	None	
22	18 44	Newhall	34 22	118 30	5	2	6	None	

Day	Approx. time 120th Mer.	Station	Approx. Lat. (N.)	Approx. Long. (W.)	Intensity R-F	Number of Shocks	Duration Sec.	Sounds	Remarks
Oct. 22	18 44	Nordhoff	34 35	119 14	5	3	6	None	Dishes rattled
22	18 44	Pasadena	34 06	118 11	5	2	30	None	Windows rattled
22	18 44	Ozena	34 53	119 16	5	2	40	Rumbling	
22	18 44	Redlands	34 04	117 12	3	1		None	
22	18 44	Riverside	33 58	117 21	3	2		None	
22	18 44	Santa Monica	34 00	118 30	5	1	10	None	
22	18 44	Surrey	35 23	118 32	3	3		None	
22	18 44	Taft	35 07	119 26	6	1	13	None	
22	18 44	Venice	34 00	118 30	3	1		None	
22	18 44	Ventura	34 16	119 17	5	3		None	
22	18 55	Avalon	33 27	118 22	3	1		None	
22	18 55	Beaumont	33 55	117 00	5	2	10	None	
22	18 55	Bakersfield	35 22	119 00	4	1		None	Shook buildings
22	18 55	Claremont	34 06	117 42	3	1	10	None	
22	18 55	Fairmont	34 45	118 25	3	2		None	
22	18 55	Gray Mountain	34 38	116 15	4	1		None	Buildings trembled
22	18 55	Los Alamos	34 44	120 16	3	1		None	
22	18 55	Los Angeles	34 03	118 15	4	1	5	None	
22	18 55	Maricopa	35 05	119 08	3	1		None	
22	18 55	Newhall	34 22	118 30	5	2	55	None	
22	18 55	Pasadena	34 06	118 11	3	1		None	
22	18 55	San Luis Obispo	35 18	120 39	2	2	4	None	
22	18 55	San Pedro	33 44	118 16	5	2	35	Faint	
22	18 55	Santa Barbara	34 23	119 40	3	2		None	
22	18 55	Santa Monica	34 00	118 30	4	1	4	None	
22	18 55	Taft	35 07	119 26	5	2	10	None	
22	18 55	Venice	34 00	118 30	3	1		None	
22	21 20	Brawley	32 59	115 40	4	1		Rumbling	
24	5 03	King City	36 14	121 06	5	1		None	
24	5 03	Lonoak	36 20	120 55	3	1		None	
24	5 03	San Luis Obispo	35 18	120 39	2	2	6	None	
Nov. 2	21 55	Calexico	32 40	115 28	5	1	30	None	
3	1 03	Santa Cruz	36 56	122 02	5	1	1	None	
3	2 05	Los Gatos	37 12	121 58	2	1	5	None	
9	1 10	Lone Pine	36 37	118 01	4	few	few	Rumblng	
26	9 05	Cahuilla	33 32	116 43	5	3	5	Rumbling	
27	23 11	Spreckels	36 20	121 48	4	3		None	
Dec. 1	14 55	Santa Maria	34 57	120 27	3	1		None	
2		San Luis Obispo	35 18	120 39	3	4		None	
7	10 55	Calexico	32 40	115 28	5	1		Rumbling	Bumping motion
7	12 30	Bishop	37 22	118 53	3	2	6	None	Trembling movement
7	12 45	Calexico	32 40	115 28	5	1		Rumbling	Bumping motion
18	11 50	Calexico	32 40	115 28	2	1		Rumbling	

of observation was, in most cases, that taken from a pocket-watch or from an ordinary clock. When an earthquake was felt at a number of stations at about the same time, it is here given as though it occurred everywhere at the same minute, though that was not necessarily the case. It is recognized that in order accurately to determine the speed of propagation of a seismic wave the timepieces required are those electrically controlled from a central station.

It is an established fact that earthquakes are more frequent in California during the night than during the daylight hours. This is all the more evident when it is recognized that in small communities slight disturbances occurring at night when most people are soundly asleep may pass entirely unrecorded. During 1916 the time of occurrence was determined in 63 earthquakes. Of these, 27, or 43 per cent, occurred during the daylight hours, 6 a.m. to 6 p.m., and 36, or 57 per cent, during the remaining 12 hours. A study of 1405 California earthquakes which occurred during 147 years from 1769-1915 inclusive, showed exactly the same distribution. While this is apparently another singular coincidence, it is worthy of mention.

That California is not homogeneous in its seismicity is also a well known fact, and might be inferred from the distribution of the recognized faults, with which all, or nearly all, of its earthquakes are associated. Especially noteworthy is the marked parallelism, along NW-SE lines, of the various physiographic features, particularly of the great folds in the crust, together with the marked variation of the topographic relief and of the geological history of the rock beneath. The fault-block origin of the Sierra Nevada, with secular elevation and depression still in progress, also promotes instability. These facts collectively explain California's high seismicity.

Figure 1 is an outline map of California showing the number of earthquakes at each of the places indicated during 1916. It is apparent that earthquakes were more frequent along the coast than in the interior, and they were more common in the southern half of the state than in the northern. This is a real and not simply an apparent difference, for the 326 observing stations are sufficiently well distributed to furnish a fair approximation in that respect. Observers are relatively few in the mountain and the desert regions, but even after due allowance is made for this fact, there was apparently an entire absence of earthquakes in the northeastern and the southeastern parts of the state. The region of greatest frequency was that in the vicinity of Monterey Bay, with 12 earthquakes reported from the town of Spreckels alone. The Imperial Valley was also a region of relatively high seismicity, Calexico having experienced 7 earthquakes. San Francisco had but one earthquake, and that was so feeble that it was felt by only a few experienced observers. Lone Pine, another recognized epicenter, had 3 shocks. Los Angeles had 4 shocks, and Redlands and Riverside each had 5 shocks.

INTENSITY

No earthquakes of destructive violence occurred during 1916 in California. The severest shocks, both of intensity VI on the adapted Rossi-Forel scale used by the Weather Bureau, occurred on July 4th and October 22d. The lighter shocks were the more frequent, generally speaking. Classified as to intensity, the reports received testified as follows: II, 24 reports; III, 49 reports; IV, 37 reports; V, 34 reports; and VI, 2 reports. The other 28 reports received gave no statement of intensity, and contained no information on which one could base an estimate. It is worthy of note that the severest shocks did not occur at the places of most frequent disturbance.

NUMBER OF SHOCKS

In the great majority of cases the number of shocks associated with the earthquakes was but one. The data presented were as follows: 1 shock, 128 reports; 2 shocks, 29 reports; 3 shocks, 13 reports; 4 shocks, 2 reports; and "few" shocks, 1 report. It should be stated that when a report of an earthquake contained no reference to the number of shocks it was assumed that but one shock occurred. If more than one occurred it was believed that the observers would have been sufficiently impressed to record the fact. A seismograph would doubtless have recorded feebler tremors in association with many of these disturbances, but only the sensible shocks are here referred to.

DURATION OF SHOCKS

As a general rule the most feeble shocks are of shortest duration, while the strongest shocks are of longest duration. The former are usually local and harmless; the latter are more or less general, and are the more destructive.

In regard to the duration of shocks, the reports received during 1916 presented the following evidence: 1 second or less, 12 reports;

2 seconds, 14 reports; 3 seconds, 9 reports; 4 seconds, 12 reports; 5 seconds, 14 reports; 6-10 seconds, 17 reports; 11-20 seconds, 8 reports; 21-30 seconds, 5 reports; 31-40 seconds, 3 reports; over 40 seconds, 3 reports; "few," 2 reports; and "blank," 75 reports.

SOUNDS

Without reference as to their occurrence before, with, or after the shocks with which they were noted, the question as to whether or not sounds were heard was answered as follows: No, 139 reports; yes, 35 reports. Here again it should be stated that unless the observers indicated otherwise, it was assumed that no sound was heard, as the report-card is so printed that an observer would not be likely to omit such an observation when made. In the 35 cases where sounds were heard they were described as follows: Rumbling, 28 reports; rattling, 3 reports; faint, 3 reports; roaring, 1 report; and loud, no reports.

NOTES ON INDIVIDUAL EARTHQUAKES

From a seismological standpoint, the year 1916 was probably a subnormal year in California. Large portions of the state experienced no earthquakes at all. For the state as a whole but two shocks were felt during March, and but one during April. There were no shocks of intensity greater than VI, and there were but two of this intensity. There was no loss of life as a direct or as an indirect result of earthquakes, and the total property loss did not exceed $1000. While there was no earthquake of special prominence, a few are worthy of mention. In the order of their occurrence, these were as follows:

February 19th. At 7:05 in the morning, an earthquake which lasted 40 seconds was felt at Bridgeport, at an altitude of 6500 feet, in the Sierra Nevada of Mono county. The intensity was estimated at III, and two distinct shocks were observed. The shocks were not felt at any other station, and were the only ones observed at this station during the whole year. Bridgeport is about 65 miles southeast of Lake Tahoe, and not far from the Major Sierra fault-system.

July 4th. At 8:41 in the evening, one of the two heaviest shocks of the year in California occurred in the vicinity of Humboldt Bay, in Mendocino county. Though no damage was done, it caused some alarm among the residents of that region. It appeared to be of greatest intensity at Ferndale, 25 miles south of Eureka, where the intensity was estimated at VI. Three separate and distinct shocks were felt at Eureka, but only one at other places near by. At Ferndale a roaring sound accompanied the disturbance.

July 16th. Two earthquakes of moderate intensity were felt during the early morning in southern California. The first one occurred at 3:50, and was felt throughout the region immediately south of the San Gabriel and San Bernardino Ranges. It was felt from Los Angeles to Beaumont, a distance of about 75 miles. The intensity appeared to increase toward the east, it being but II at the former station, and V at the latter. At 4:30 a.m., but 40 minutes after the first one, a second shock was felt throughout an equally large area just northeast of the region affected by the first disturbance. It was felt from Riverside, where the intensity was II, to Barstow, 80 miles to the northeast, where the intensity was V. A portion of the same region, in the vicinity of Riverside and Redlands, was again disturbed by a slight shock on July 27th. As this portion of California is traversed by a complex system of known faults, in addition, presumably, to others which are still problematic, it would be difficult to determine to which fault or faults these disturbances should be ascribed.

August 6th. At 11:40 a.m. an earthquake was felt along a narrow belt extending from Sausalito on the north to Paso Robles on the south. The territory affected was about 175 miles long, and not more than 50 miles wide. On the north the intensity appeared to be II to III, while near its southerly limit the intensity was estimated at IV to V. At San Francisco it was felt by only a few experienced observers, and was the only sensible earthquake observed during the entire year. On the east side of the Bay it was not felt by anyone, so far as is known. At Spreckels, where the intensity was V, two distinct shocks were felt, but elsewhere only one was observed. At 12:55 p.m. on the same day, or an hour and fifteen minutes after the first disturbance, a second shock was felt at Hollister, Salinas and Spreckels, or throughout a small area just east of Monterey Bay. This consisted of but one jar, and the intensity was again estimated at V at Spreckels. Further disturbances were reported from this comparatively narrow region extending from Monterey Bay southeastward about 150 miles to Los Alamos. One earthquake was felt on August 7th, three on August 8th, one each on August 31st, September 6th, 8th, 27th, October 22d and 24th, two shocks on November 3d, one on November 27th, and still another on December 2d. Spreckels alone experienced 12 earthquakes during the year, the greatest number for any one station in the state. Earthquakes occurred at some place or other in this narrow belt on 26 occasions during the year.

August 23d. At 6:55 a.m. an earthquake of moderate intensity occurred in the vicinity of Humboldt Bay, the second of the year there. The region affected was comparatively small, not more than a few miles wide, and about 35 miles in length, extending southeastward from the bay. The intensity was estimated at V at Eureka, where the shock was strongest. There two distinct shocks were felt, and the vibrations persisted through about 30 seconds of time. A rumbling sound accompanied the disturbances. At Rohnerville three shocks were noted, and the intensity was estimated at IV.

September 29th. At 4:20 a.m. a slight earthquake was felt at Calexico, in the Imperial Valley. The area affected must have been very small, as it was not reported from any other station. At 6:11 p.m., however, a moderately strong shock was felt throughout a large region south of the San Gabriel - San Bernardino Range, and west of the Imperial Valley. It was observed as far southward as San Diego, and doubtless it extended southward into Mexico. The intensity varied from II to V, and the number of shocks from one to two in different places. The vibrations appeared to continue an unusually long time,—for 60 seconds at one station, Palm Springs. Observers reported the shock from 17 different stations, and at more than half of these, sounds accompanied the disturbance. About two hours and fourteen minutes later, or at 8:25 p.m., another earthquake of intensity IV to V was felt in a portion of the Imperial Valley which had been undisturbed by the two earlier shocks of the same day. From Indio to El Centro one distinct shock was felt, and at the latter place the vibrations were perceptible through 50 seconds of time. No earthquake was felt at this time at Calexico.

October 22d. The strongest and most widely-felt earthquakes of the year occurred at 6:44 p.m. and 6:55 p.m. on this date. The first one was felt throughout an area of about 300 miles in length and less than 100 miles in width, extending from Fresno on the north to Redlands on the south. In different places the intensity varied from II to VI, the number of shocks from one to four, and the duration from 4 to 40 seconds. Of the 20 places in which the disturbance was felt, accompanying sounds were heard by only three observers. The second earthquake was felt throughout a shorter but wider area just west of that affected by the earlier shock. With this one the intensity varied from II to V in different places, the number of shocks from one to two, and the duration from 4 to 55 seconds. Of the 17 stations reporting this earthquake, sounds were noted at but one, and in that instance the sound was described as "faint." Many and varied phenomena were caused by these twin shocks. Waves 8 to 10 inches high rolled in on the west side of Buena Vista Lake for at least one hour after these shocks, and there was no wind blowing at the time. Near Maricopa, in the Kern county oil-fields southwest of Bakersfield, an oil-well that had been dormant for more than two years suddenly resumed its flow. The Edison Company's power-line between Bakersfield and Los Angeles was broken. At San Bernardino the patients in the county hospital became so badly frightened that some time elapsed before they could be calmed. While the statement could not be verified, the press reported that a certain deep well located in the San Joaquin Valley temporarily became a geyser, and in the water ejected there were found a number of small fish without eyes, similar to fish which inhabit subterranean waters.

General Considerations

Perhaps the most conspicuous feature of the year in California from a seismological viewpoint was the pronounced activity in the region immediately east and southeast of Monterey Bay. When 26 sensible earthquakes occur in a single year in a comparatively small area, such as occurred during 1916 in this region, the disturbances naturally invite attention. This region has long been subject to frequent shocks of light to moderate intensity, but the activity has become more pronounced of late. During 1915 seven earthquakes were reported from this region. Most seismologists agree that a great shock of destructive force is preceded for months, and in some cases for years, by an increasing number of light shocks. With this principle in mind this region should be watched with interest in the near future. (The same remark may be applied with equal force to that portion of the state extending southeastward from the San Gabriel Range to the Mexican border.) In the Monterey Bay region there are several active faults which individually or collectively may explain the disturbances. The great San Andreas fault traverses the region, and is crossed nearly at right angles by the Pajaro fault, but 15 miles in length. The Santa Lucia fault along the eastern base of the mountain range of that name, traverses the Salinas Valley for about 100 miles. In addition, it is suspected that there is an active submarine fault not far to the west. The evidence submitted on the report-cards is too meager to form a basis for judging which of the numerous recognized faults in California is the cause of any particular earthquake, or of pronounced activity in a certain region. For this reason no attempt is made in this discussion to ascribe movement along any one fault as the cause of a given earthquake, although it is regarded as reasonably certain that all, or nearly all, earthquakes occurring in California are so caused.

On the other hand, diminished seismic activity in other portions of the state is no less interesting. In the Imperial Valley, the most disturbed portion of the state during 1915, only a few, light shocks were noted during 1916. At Brawley, where 14 shocks were felt during the preceding year, but 2 were noticed during the past year. At Calexico, where 2 destructive shocks (intensity VIII) and numerous slight shocks occurred during 1915, but 7 shocks, all of them slight, occurred during 1916. In the Owens Valley, a region of great seismic agitation a few decades ago, but 3 feeble shocks were reported during the past year. San Francisco, with an international reputation for earthquakes, had but 1 tremor during 1916, and that was so slight that it was felt by only a few persons.

Lassen Peak (lat. 40° 25′ N., long. 121° 45′ W.), apparently a true volcano, has shown activity sporadically during the year 1916. There is good evidence that it was on the decline during the year, however, and that its present cycle of agitation has about run its course. As in 1915, so in 1916, no earthquake which occurred in California could be explained even remotely in terms of Lassen's vulcanism.

Though related to seismology only in a negative sense, another somewhat similar matter is worthy of interest. On August 22, 1916, the Associated Press reported the occurrence of "an eleven-minute eruption last night of an unnamed volcanic peak about 25 miles south of here (Calexico) in Lower California." This is in the Imperial Valley, just across the Mexican boundary. A request for further information was addressed to Mr. C. R. Rockwood, Chief Engineer of the Imperial Irrigation District, who kindly replied as follows:

Replying to yours of September 9th, the eruption referred to was not a new and unnamed volcano. At a point about two and one-half miles to the south of Black Butte is a section of country covering possibly thirty or forty acres where geysers are very active. This section is known locally as the Volcanoes. Usually these mud volcanoes are more active in the early morning than at any other time of day, but during the past year I have noticed at times that they become very active at other times during the day.

The eruption referred to in the San Diego *Union* occurred about four o'clock in the afternoon, and was the most violent that I have ever observed during the many years that I have been in this locality. The explosions lasted through a period of eleven minutes, during which time I presume there must have been 100 distinct explosions covering a lateral area of 1500 feet wide, each individual explosion being from 20 to 100 feet in width, throwing up columns of mud and steam to a height of 600 or 700 feet.

Previous to this I have never witnessed one of these explosions that threw mud into the air to a height greater than 200 feet; while ordinarily the height is but 15 to 50 feet.

The active explosions are in a submerged area, small in extent. This, however, is surrounded by a wider area of sulphur cones; while the hot sulphur springs extend for several miles both to the north and south of the more active center.

There was no earthquake at the time. Personally I have not felt an earth tremor for several months, although I understand that there was one about a month ago. As you request we will report to you any shocks that may occur.

Seismological Work in California

The seismological work of the Weather Bureau in California is proceeding as originally planned. The work thus far has been chiefly seismologic rather than seismographic; that is, it has been concerned mainly with the collection of records of earthquakes sufficiently strong to be felt by persons, rather than the securing of automatic records. Eventually the Bureau may have seismographs of its own in California.

In conducting this new work in California the Weather Bureau hopes to secure a complete record of all earthquakes in this state. Members of the Seismological Society of America are invited to co-operate in this work, particularly those members residing in or traveling through portions of the state away from the larger cities. Cards for reporting earthquakes will gladly be furnished.

The seismological records of the Bureau have already been found of service to the public. Representatives of insurance companies have consulted the records in considering claims for damages reported to have resulted from earthquakes. On one occasion a representative of the Bureau was summoned to court to testify regarding the frequency and the intensity of recent earthquakes in San Francisco. A request for expert testimony was denied. Following even a slight shock the San Francisco office invariably receives numerous requests for information, both from the general public and from the press. However, for reasons best known to themselves, the newspapers rarely give California earthquakes any publicity.

In connection with this work various problems have arisen from time to time which invite attention. A few of these are enumerated in the following paragraphs.

In an investigation of gas rates conducted by the State Railroad Commission a representative of one of the public service corporations operating extensively in northern California testified that earthquakes are a cause of leakage of gas from underground gas mains. As the loss is eventually borne by the consumer it appears that the public interest would be served by a study of the problem with a view of preventing this loss, if possible.

Various Japanese investigators have found that the barometric gradient offers a means of discovering unknown seismic zones or faults, as it was shown that the prevailing gradient at the time of an earthquake was nearly perpendicular to the seismic zone. The method was found more feasible and more accurate than that of constructing the zones statistically by locating a large number of epicenters. In California, with well developed gradients occurring during the winter half-year, and with frequent earthquakes occurring throughout the year, this method offers an opportunity for some student of seismology to do useful work in locating fault zones which are still unrecognized.

In a region of little or no cloud can a telescope be adapted to serve as a delicate seismograph? Professor E. C. Pickering, of Harvard, has designed a meteorological instrument known as the Pickering Pole Star Recorder, which, by taking a continuous photograph of Polaris at night gives a basis for estimating the amount of cloudiness which has occurred. As Polaris is not exactly at the north celestial pole, the star's image focussed upon a photographic plate will make a semicircle on cloudless nights, broken on partly cloudy nights, and entirely absent on overcast nights. At least three of these instruments are in successful operation in New England at the present time. Though not intended as a seismograph, would not an earthquake record itself upon the sensitized plate also? It seems a comparatively simple matter thus to transform a small and inexpensive telescope into a sensitive seismograph. This idea was suggested by the following note, submitted by Mr. Wendell P. Hoge, of the Mount Wilson Solar Observatory, in reporting an earthquake of intensity I which occurred March 22, 1916:

> This disturbance noticed while watching star image in 60-inch telescope, using high-power eyepiece. Oscillations of the star image in the field rapid and short at first, becoming more marked in the middle and diminishing at the end of the disturbance. Evidently a very faint shock. Mr. G. A. Monk, using the instrument a little later, at 4:50 and 4:56 a.m., noticed two very feeble oscillations.

The psychological effects of earthquakes would seem to offer an interesting thesis subject for some graduate student of psychology. The mental effects upon human beings of such common natural phenomena as thunderstorms and earthquakes have not yet received the careful attention they deserve. With the occurrence of even a mild thunderstorm some persons are precipitated into a kind of hysteria, while other persons show no reaction whatever. The same may be said of earthquakes. Moreover, with certain earthquakes some people hear sounds and occasionally detect unusual odors. In recording personal impressions made by an earthquake, personal equation enters perhaps more completely than in the observation of any other natural phenomenon. The whole problem invites attention. California would seem a fitting field for a study of this nature.

A discussion of California earthquakes would be incomplete if it did not refer to the personal danger from and the damage done by such shocks. From the data presented above it is evident that California is a region of high seismicity, in fact the highest in the United States. Violent and destructive earthquakes have occurred in the past and are extremely likely again to occur in the future. When or where they will occur is beyond the possibility of forecast at the present time.

Residents of California realize perhaps more fully than their friends in the East that the danger to the individual is really very slight indeed. While for the state as a whole the total number of earthquakes in one year appears large, that for any one locality is comparatively small. Moreover, the great majority of shocks are so light as to be harmless, those of destructive intensity occurring but once in a number of years, for the state as a whole, and rarely occurring more than two or three times in a century in the most unstable region. Furthermore, steel-frame buildings of modern construction are sufficiently strong to withstand shocks as severe as any of which there is any authentic record in California. The total property damage in 1916 was less than $1000, an amount of damage exceeded by any one of more than a thousand lightning discharges which occur every summer in the eastern United States. As a matter of fact, earthquakes are far less destructive in California than are the thunderstorms and the tornadoes and the hurricanes of the East and South.

San Francisco, Cal.,
January 20, 1917.

A NEW LIQUID DAMPING CONTRIVANCE FOR SEISMOGRAPHS

By Alix Lemos, Assistant, National Observatory, Rio de Janeiro.
(Translated by Assistant Sampaio Ferraz.)

The magnification of a seismograph is considered to be the relation between the angular displacement ϑ, that is, the arc described by the writing point, and the arc which would describe for an equal displacement an equivalent simple pendulum whose length of string is L.

If we represent the first arc by a, we shall get the known expression

$$V = \frac{a}{L\theta},$$

in which V is the magnification.

This formula, however, only gives the effective ampliation of the earth vibrations when these are very rapid, since we know that if the period of the seismic waves, which we will call T_e, approximates the period T_0 of the pendulum, the arc a increases exaggeratively, becoming theoretically infinite when $T_e = T_0$; starting, however, from this value, if T_e increases, a diminishes. The equation above being inapplicable to such cases, we see, thus, that its value cannot supply us with a basis by which we may measure the magnitude of the earth movements.

Wiechert, however, demonstrated that, even in such conditions, analyzing the seismogram, the real amplitude of the earth movements could be given by the formula

$$W = \frac{V}{\sqrt{\left[1 - \left(\frac{T_e}{T_0}\right)^2\right]^2 + 4\,\frac{(nat.\ log.\ \zeta)^2}{\pi^2 + (nat.\ log.\ \zeta)^2}}\left(\frac{T_e}{T_0}\right)}$$

as long as the pendulum would be conveniently damped. The precision of our estimations depends therefore on the amount of damping.

In the Reports of the International Seismological Committee (St. Petersburg, 1910, vol. 3), kindly translated by our Director, Dr. H.

UM NOVO DISPOSITIVO DE AMORTECIMENTO LIQUIDO PARA SISMOGRAPHOS

Por Alix Lemos, Ajudante, Observatorio Nacional, Rio de Janeiro.

Considera-se, como ampliação do sismographo, a relação entre o arco, que corresponde ao desvio angular ϑ, descripto pelo estilete registrador; e o que, para igual desvio, descreveria o pendulo simples e equivalente de comprimento L.

Se designarmos, pois, por a o arco a que, primeiramente, nos referimos, teremos a relação conhecida

$$V = \frac{a}{L\theta}$$

sendo, então, V a ampliação definida.

Esta fórmula, porém, só fornece o augmento effectivo dos movimentos do sólo, no caso de serem os mesmos bastante rapidos. Porquanto, sabemos que, se o periodo da particula terrestre, que designaremos por T_e, approxima-se do periodo proprio T_0 do pendulo, o arco a augmenta exageradamente, tornando-se theoricamente infinito para $T_e = T_0$. Á partir, no emtanto, desse valor, se T_e ainda augmenta a diminue; de sorte que o seu valor não nos póde servir de criterio para avaliarmos a grandeza do deslocamento do sólo; sendo a fórmula acima inapplicavel á taes casos.

Wiechert, porém, demonstrou que, mesmo em taes condições, poder-se-hia deduzir, da analyse do sismogramma, a amplitude real da vibração da particula terrestre, pelo emprego da fórmula:

$$W = \frac{V}{\sqrt{\left[1 - \left(\frac{T_e}{T_0}\right)^2\right]^2 + 4\,\frac{(lg.\ nat.\zeta)^2}{\pi^2 + (lg.nat.\zeta)}\left(\frac{T_e}{T_0}\right)^2}}$$

desde que o pendulo fosse convenientemente amortecido. Do amortecimento, portanto, depende em grande parte a precisão da nossa avaliação.

Nos C. R. das Sessões da Commissão Sismologica Internacional (Tomo 3, S. Petersbourg, 1910), cuja traducção devemos á benevo-

Morize, Prince Galitzin, the greatest authority on the matter, says: "Before anything the instrument must correspond to the differential and fundamental equation of the pendulum swing; especially its own period, without damping, must be independent of the amplitude of the oscillation, and the moment of the damping force must be, in effect, proportional to the angular velocity. It is equally necessary that, to avoid the influence of the pendulum's own motion, it should be strongly damped and at the same time possess a high sensitiveness."

In the Bosch-Omori pendulum of 100 kg. mass, our standard instrument, the damping is obtained by the resistance which the air offers to the displacement of a plate piston inside a cylinder with two holes whose size can be regulated.

In principle the contrivance is simple enough, but it has several inconveniences, the chief one being the difficulty of obtaining aperiodicity, without which we have no means of avoiding the resonance troubles. Another defect lies in the resistances, principally the friction produced by the device which holds the damping-plate to the seismograph, and those that arise from the pendulum itself, reducing its sensitiveness. Yet another serious disadvantage, also mentioned in Galitzin's note given above, is the diminishing effect of the damper on the pendulum's period, even when its holes are completely opened.

These faults led us to search for another means of damping; it being impossible to resort to the electromagnetic arrangement, as there are not for sale in our market permanent magnets strong enough for our purpose, we tried the liquid damping.

We attached to the horizontal pendulum boom a light vertical aluminum rod with a metallic disc at its inferior extremity immersed in the damping liquid—glycerine—placed in a glass vessel: to avoid the hydration of the liquid, a thin layer of petroleum is maintained over its surface. The first trials were not sufficiently satisfactory, as the damped curve revealed slight parasite oscillations which appeared to be produced by vibrations developed in the liquid itself; these oscillations were naturally exaggerated on account of the small size of the vessel employed. To obviate this we then proposed to extinguish or at least damp such vibrations: that is, do away with the energy impressed by the pendulum's oscillations on the damping liquid chosen; to do this we employed a metallic-gauze cylinder concentric to the outer vessel and only big enough to allow the free displacement of the damping-plate disc.

lencia do nosso illustre Director, Dr. H. Morize, assim expressa-se, o Principe Galitzine, a maior authoridade no assumpto: "Antes de tudo devem realmente corresponder os apparelhos á equação differencial e fundamental do movimento pendular, especialmente o seo periodo proprio, sem amortecimento, deve ser independente da amplitude da oscillação, e o momento da força de amortecimento deve ser realmente proporcional á velocidade angular. É igualmente necessario que, para evitar a influencia do movimento proprio do pendulo, seja este fortemente amortecido e, com isto, ainda possua alta sensibilidade."

No pendulo Bosch-Omori, de 100 kgs., que nos serve de padrão, o amortecimento é obtido pela resistencia que o ar offerece ao deslocamento, de uma placa metalica, dentro de uma camara; cuja communicação com o exterior póde ser regulada pelo fechamento, mais ou menos completo, de duas janellas circulares e lateraes.

Em principio é simples o dispositivo, mas, no emtanto, apresenta alguns inconvenientes.

O principal reside na difficuldade de tornal-o aperiodico, porquanto, não o fazer, seria dar lugar ao phenomeno que se trata de evitar: o da resonancia.

Outro defeito consiste nas resistencias, principalmente attrictos, que o dispositivo de ligação, da placa amortecedora ao sismographo, introduz; e que addicionam-se aos do proprio pendulo, diminuindo a sua sensibilidade.

Outra, e bastante seria desvantagem, é a diminuição do periodo proprio do pendulo, quando ligado ao amortecedor, embora esteja este com as janellas completamente abertas; facto a que tamben refere-se o Principe Galitzine, na communicação já citada.

Estes defeitos levaram-nos á estudar um outro meio de amortecimento; na impossibilidade de empregarmos o electro-magnetico, pois não temos, no mercado, imans permanentes de força adequada ao nosso caso; experimentamos o amortecimento liquido.

Para isso prendemos, á haste horizontal do pendulo, uma vertical e pequena, de aluminio, terminada inferiormente n'uma placa metalica leve, imersa no liquido amortecedor: a glycerina. Esta, collocada em um recipiente cylindrico de vidro, é impedida de hydratar-se, por meio de uma leve camada de petroleo.

Os primeiros ensaios não nos deram resultados bastante satis-

With this device we obtained good results, as can be seen by the curve which accompanies this paper. It is obvious that by attaching the damping-plate directly to the pendulum we avoided the friction to which we referred above, preserving all the sensitiveness of the seismograph. Thus, with the old damping arrangement we obtained a 12 mm. deflection employing a weight of 0.5 grams, whilst with the new liquid contrivance the deflection of the writing-point for the same weight was observed to be 24 mm.; in both experiments the inclina-

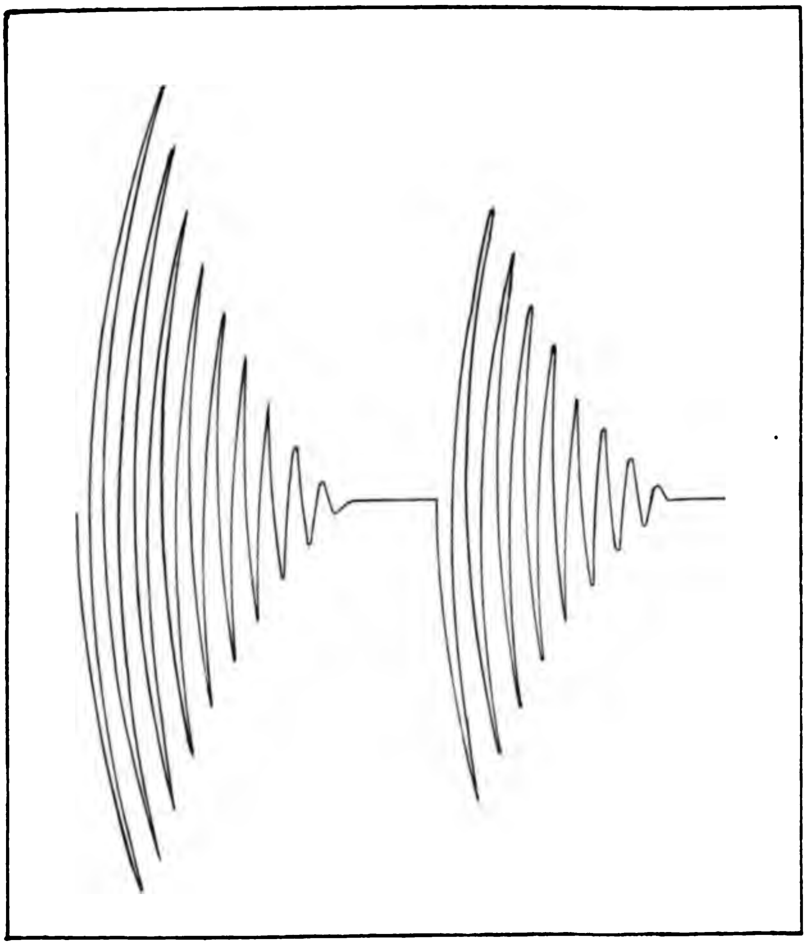


Fig. 1. Record without damping.

factorios, pois, notava-se na curva amortecida, ligeiras oscillações parasitas, que pareciam provir de vibrações desenvolvidas no proprio liquido; e exageradas em consequencia das pequenas dimensões do recipiente empregado.

Occorreu-nos, então, dissipar ou, pelo menos, amortecer taes vibrações, isto é, destruir, tanto quanto possivel, a energia impressa ao liquido amortecedor pelas oscillações do pendulo; para isto, empregamos uma tela metallica cylindrica, concentrica ao vaso e permittindo, apenas, o deslocamento da placa amortecedora.

Com tal dispositivo, obtivemos pleno successo, como pode-se avaliar pelo exame da curva que, a estas notas, acompanha. É claro que, com a ligação directa da placa de amortecimento ao pendulo, evitamos os attrictos á que acima nos referimos; conservando o sismographo toda a sua sensibilidade. É assim que, desviando-o com um peso de 0.5 gr., obtivemos um desvio do estylete de 12.0 mm., quando ligado ao antigo amortecedor, ao passo que, com o actual, obtemos 24.0 mm.; sendo identico o angulo de inclinação em ambas as experiencias.

Além d'isso o periodo proprio do pendulo que elevava-se, apenas, á 12.0 s., passou á ser de 24.0 s.

Quanto ao coefficiente de amortecimento que, com o antigo, variva com a amplitude da oscillação segundo lei complexa, com o actual amortecedor, pouco varia, sendo essa diminuta variação approximadamente proporcional á mesma amplitude; para amplitudes respectivas de 22.0 mm.; 49.0 mm. e 52.0 mm., obtivemos os seguintes valores para o coefficiente ζ: $\zeta = 2.3$, 2.6 e 2.7.

Na determinação do valor da ampliação V, empregamos a fórmula de Wiechert para os seus pendulos invertidos; e que tambem applicase ao nosso caso. Com effeito:

Se desviarmos um pendulo horizontal, de massa M, da sua posição de equilibrio, o momento da força restauradora é, como sabemos, approximadamente igual á $M\,g\,i\,l$ sen ϑ; sendo ϑ, o desvio angular; i a inclinação do eixo do pendulo em relação á vertical; g, a accelleração local da gravidade; e l, a distancia do centro de massa ao eixo de rotação do systema. Se o mantivermos, porém, em equillibrio, quando desviado pela força applicada, e que designaremos por f, é claro que expressaremos a nova condição de equillibrio, escrevendo que o momento da segunda força é igual e contrario ao da primeira, isto é, fazendo $M\,g\,i\,l$ sen $\vartheta = fl'$ cos ϑ sendo l', o braço de alavanca de f.

tion angle was the same. Moreover, the pendulum's own period was increased from 12 to 24 seconds.

With the old damper the damping coefficient varied with the amplitude of oscillation according to a complicated law; now, with the present arrangement, the coefficient hardly varies, and the minute variation noted is approximately proportional to the amplitude of oscillation; for amplitudes of 22, 49 and 52 mm. we obtained the following values for the coefficient ζ: 2.3, 2.6 and 2.7, respectively.

In determining the magnification value, V, we employed Wiechert's formula for his inverted pendulum, which can also be applied to our case. In fact, if we displace a horizontal pendulum with mass M from its position of equilibrium, the moment of the re-establishing force is, as we know, approximately equal to $M g i l \sin \vartheta$, in which ϑ is the angular displacement; i is the inclination of the pendulum's axis to a vertical plane; g is the local acceleration of gravity; and l the distance from the center of the mass to the rotation's axis of the system. If, however, we maintain the horizontal pendulum in equilibrium, when it is displaced by the application of a force which we may call f, it is clear that we express the new condition of equilibrium by saying that the moment of the latter force is equal and opposite

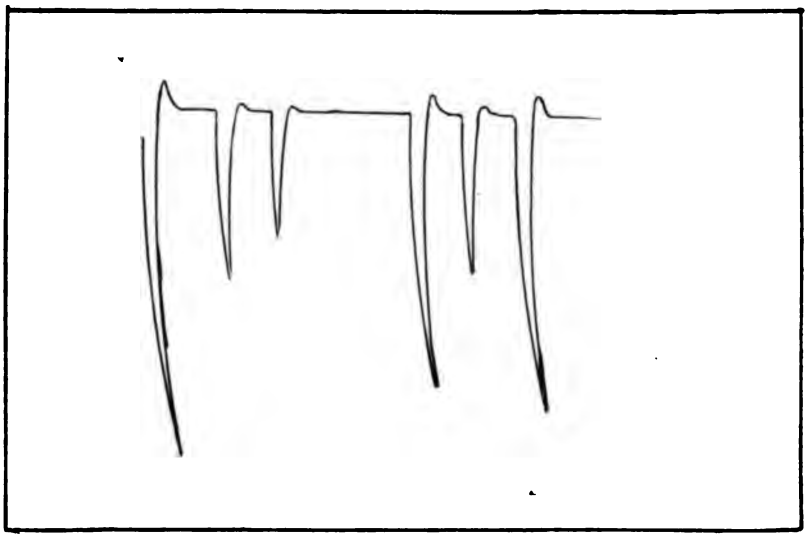


Fig. 2. Record with damping.

No caso de ser a força desviante um pequeno peso de massa m, applicado ao centro de gravidade do systema, teremos:

Mi sen $\vartheta = m$ cos ϑ, e como ϑ é muito pequeno, virá:

$$Mi\vartheta = m.$$

D'esta ultima igualdade deduz-se:

$$\theta = \frac{m}{Mi} \text{ e como } L = \frac{T_0^2}{4\pi^2} gi = n.^2 i,$$

sendo n uma constante, teremos:

$$V = \frac{a}{L\theta} = \frac{Ma}{mn^2},$$

fórmula identica á de Wiechert.

to the former: that is, making $M g i l \sin\vartheta = f l' \cos\vartheta$, where l' is the arm of the lever of f.

In the case of the deflecting force being a small weight of mass m applied to the center of gravity of the system, we have

$$Mi \sin\vartheta = m \cos\vartheta,$$

and since ϑ is very small, we may say

$$Mi\theta = m \text{ or } \theta = \frac{m}{Mi}.$$

Since
$$L = \frac{T_0^2}{4\pi^2} gi = n^2 i$$

where n is a constant, we shall have

$$V = \frac{a}{L\theta} = \frac{Ma}{mn^2},$$

which is the same as Wiechert's formula.

NOTE ON THE EARTHQUAKES AT ALMIRANTE, REPUBLIC OF PANAMA, IN APRIL 1916

By Harry Fielding Reid

The following account of the strong earthquake which occurred in the western part of Republic of Panama on April 25, 1916, and was felt in the Canal Zone, has been sent by Mr. F. D. Willson, Chief Hydrographer of the Isthmian Canal Commission. It was written by Mr. E. C. MacFarlane, who lives at Bocas del Toro, but who writes from Almirante; it is published with his permission.

Almirante is situated on Almirante Bay, on the north side of Panama and 175 miles west of Colon, in latitude N. 9° 30′ and longitude W. 82° 30′. Bocas del Toro is on an island at the entrance of the bay, and about six miles east by north from Almirante. The G. M. T. of the shocks was determined from the seismographic records at Balboa Heights, C. Z., Viequez, P. R., and several observatories in the United States.

At 2:45 a.m. Monday, April 24th (8h 01m 44s, G. M. T.) quite a heavy earthquake was felt here, and from later reports its center must have been in this immediate neighborhood. In some houses it knocked over glasses, pitchers sitting in bowls turned over, as did a few other articles, but practically no damage resulted. It was, however, the heaviest shock experienced here during the last eight years. During Monday and Tuesday many tremors were felt.

Tuesday night, April 25th, at 9:03 (2h 21m 52s, G. M. T., April 26th) came the climax,—the one of Monday was as nothing in comparison. With a friend I had just stepped off the platform of the Merchandise Department warehouse, when we noticed about a dozen of the employees of the Accounting Department rushing from the office and almost at the same instant the hard shock commenced and lasted, I should say, at least thirty seconds. We could only remain standing by holding each other, but kept our eyes fixed in a fascinated sort of way on the three-story reinforced cement building, which must have swayed two feet from the perpendicular in a direction east to west. Later we saw that it must have done the same thing north to south—from the way the earth at the foundations had receded.

There are thirty-six steel lockers and any number of steel filing cabinets and glass-front bookcases in the office, to say nothing of all the furniture in the quarters on the second floor and equipment in the dining-room and kitchen on the third floor. In the Merchandise warehouse back of us were hundreds of cases and crates of every sort of merchandise. The din caused by all these things crashing to the floors, together with chunks of concrete and hundreds of window-panes, was deafening. And in the distance houses, water-tanks and stacked-up lumber could be heard falling to the ground. It was a conglomeration of sounds no one who heard will soon forget. Of course all the electric lights in town went out, which added to the confusion. Fortunately there was little damage to the wiring, and the lights were on again in less than ten minutes. The "Abangarez" searchlight kept playing on the town, which helped some. Six fires started in laborers' quarters, but were quickly put out by chemical extinguishers. All water-mains were temporarily out of business.

All merchandise on shelves was thrown to the floors, and eighty-nine houses at Almirante and at a place one mile distant slipped off their pins and sat down on the ground in a more or less graceful position—principally less.

The railway track was curiously kinked in several places, without rhyme or reason, and the quake played many curious pranks. One china-closet overbalanced, the door opened, and everything crashed to the floor; the closet regained its normal position uninjured and the door closed. Two shoe-trees under a bed about ten feet from a clothes-closet, were found, one under each front leg of the closet; they had met about half way. In many cases of bottled goods every bottle in an unopened case was broken. In some instances everything breakable in one room of a house was destroyed, while in the next room nothing seemed to have been moved.

At Bocas a slight tidal wave carried canoes and debris two hundred meters inland. Sweet water was found in one of the cracks in the street, and is still causing considerable speculation. Near this spot several years ago an artesian well was driven twelve hundred feet and no water, either salt or fresh, was encountered.

At Bocas and up country no damage at all is reported, and the shock seems to have been slight in comparison with our experience. There is, therefore, no question that the center of this shock was also at Almirante or near by.

The telephone cable connecting Bocas with the mainland was pulled apart in two places, the strange thing being that the wires were drawn to about the size of a coarse hair before they finally parted. Six corporation cocks were torn in two just where the thread stops at the body. Each one of these was a perfect casting originally.

Other tremors have been felt since, the most noticeable being at 3:05 this morning (April 28th), when all the over-excited inhabitants of the town got out of their houses as promptly as circumstances permitted.

Fortunately not a soul was the slightest bit injured, but the property damage will amount to between $20,000 and $25,000, United States currency.

The weather on Tuesday was extremely oppressive—close, sultry and dead calm—ideal earthquake weather according to popular opinion. The sky at sundown had a most peculiar aspect, what they call in Costa Rica (according to one of the Costa Ricans who was present at the Cartago disaster) a "stony" sky, the clouds resembling boulders. This Costa Rican and a man who was in Kingston during their earthquake, claim the shock we had was stronger than either of these just mentioned. The counter-motions here were evidently not as many as in either place.

The breaking of the cable and the small tidal wave at Bocas suggest that the origin of the shock was in the bay. The very strong intensity in Almirante places the origin very near that place. Mr. MacFarlane writes me that Almirante is situated at the head of a cove so well protected by headlands and islands that the water is always smooth. This accounts for the absence of any tidal wave at Almirante. The tidal wave reported at Bocas del Toro came from the northwest.

The earthquake of April 24th was evidently a forerunner of the stronger shock; both of them were felt in the Canal Zone, the former with an intensity of III-IV, the latter with an intensity of V; the second stopped pendulum clocks at Colon and at Balboa Heights. The intensities of the shocks at Almirante were VII and VIII-IX, respectively. Frame houses set up on underpinning are not very stable; it does not require a destructive shock to overthrow the pins and let the houses down. The seismographs at Balboa Heights made excellent records of the shocks up to the time the pens were carried off the recording drums. The earth amplitude at Balboa Heights was about 7 mm. for the earlier shock and probably more than 10 mm. for the later; no damage of any kind has been reported from the Canal Zone. The seismograms show well the first preliminary tremors, which correspond to the longitudinal waves; as might be expected, they are stronger on the E-W component than on the N-S. The second preliminary tremors, which represent the transverse waves, are not separated from the long waves; they were larger on the N-S component than on the E-W. The strongest movement recorded belongs to this part of the record.

The seismographs recorded after-shocks at 5:41:25, 6:26:43, 7:17:20 and 12:41:56, G. M. T., April 26th. To get the time at the origin we must subtract 44 seconds from these times; and then subtract 5 1-4 hours to find the local time of Almirante. On May 10th the seismographs recorded a strong shock at 21:57:20 G. M. T., which probably occurred in the neighborhood of the former shocks, but has not been reported; the local time at Almirante would be about 4:40 p.m. The earth amplitude at Balboa Heights was 5 or 6 mm.

The shock of April 28th, though strongly felt at Almirante, was barely recorded in the Canal Zone, the greatest earth movement there being only about .01 mm.

THE MEXICAN EARTHQUAKE OF NOVEMBER 12, 1912

By Count de Montessus de Ballore

When a destructive earthquake opens a fault in the earth's surface, seismological observations alone do not usually show which parts of the ground have been uplifted and which depressed on the opposite sides of this seismotectonic line, and in only a few cases have new geodetic measures afforded the solution of the problem in an epicentral area where a previous triangulation has been made. On the contrary, on the occasion of the Mexican earthquake of November 12, 1912, we can investigate the subject without the help of another science, and for this purpose we have as a very good base the observations made on the ground soon after the disaster, by the state geologists Urbina and Camacho.[1]

That earthquake happened on the high Anahuac table-land along the 20th parallel, and at equal distances between Queretaro and Mexico. Its epicentral or megaseismic area forms a trapezium, the northern and southern bases of which were two faults opened by the earthquake, with respective lengths of 50 and 19 kilometers, while their distance apart was 19 kilometers. Another parallel earthquake fault was opened also in the interior of the trapezium.

The geomorphogenic and geologic features of this area do not suggest to us any hypothesis in regard to the nature of previous tectonicoseismic movement, for the rocks of the region are volcanic, principally hypersthene andesite, and their stratigraphy and geologic ages are not certainly known. It is to be noted, however, that the northern seismic fault and two other interior faults shown on the map follow a line of hills having the same direction, while the oblique sides of the trapezium lie in alluvial depressions, the valley of Lerma River on the west and the plain of Huapango Lake on the east, features without any tectonic significance. We are therefore obliged to use only seismological observations for interpreting the tectonic movement of the earthquake, but these are quite sufficient in spite of these unfavorable circumstances, as we shall see presently.

---

[1] La zona megaséismica Acambay-Tlxmadeje, Estado de Mexico, conmovida el 12 de Noviembre de 1912. Bol. Inst. Geol. de Mexico, no. 32, 1913.

Throughout the interior of the epicentral trapezium the intensity reached IX and X, while it decreased very suddenly three or four degrees in the surrounding area, though the movement was felt to great distances, especially toward the south, so that the surface area affected was not less than one hundred thousand square kilometers. This sudden decrease of the intensity is alone a sufficient proof that the earthquake was caused by a block movement of the terrestrial area bounded by the northern and southern seismic dislocations. And many other facts can be adduced in support of this theory.

At twenty-one places within the epicentral area the direction of the first seismic impulse was determined by good observers or by investigating damaged or destroyed buildings, and at the remarkable number of seventeen points it has been ascertained that the initial movement was directed towards the interior. The deduction is the same as that stated above.

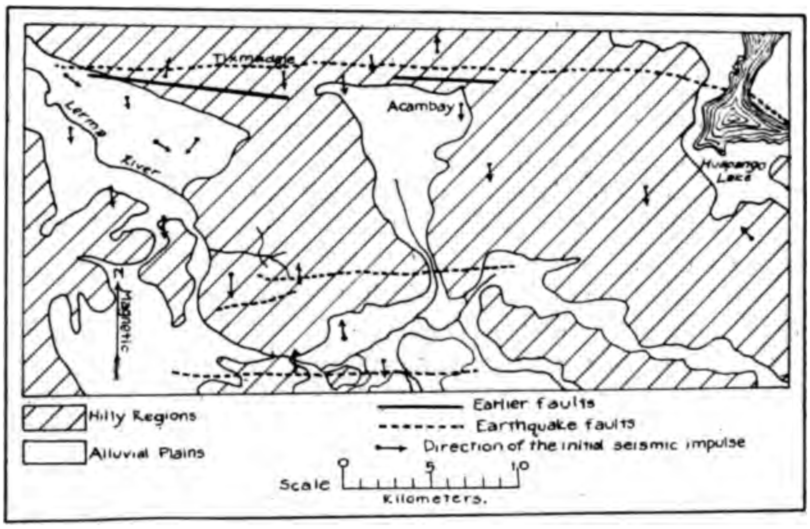


Fig. 1. Mexican Earthquake of November 12, 1912. (After Urbina and Camacho.)

We have now to describe briefly the seismic dislocations. There are three: that is to say, the bases of the trapezium, and another, having the same east-west direction, but situated in the interior. These faults are not continuous, but they form a series of lineal interrupted rents, with an uplift which almost always faces inwards toward the trapezium and which amounted to only fifty or sixty centimeters. Sometimes there are two or three parallel rents very close together. The interior fault is bifurcated. It has not been possible to measure the depth of the rents, for their edges had already fallen down or were otherwise obliterated when the geologists arrived. It was determined at one point, however, for the northern fault crossed a water-supply tunnel for the town of Acambay. This work was broken and displaced at a point eleven meters below the surface, so that we have the minimum depth to which the strata have been dislocated. In some points along the Lerma River banks the alluvial soil had subsided in the form of parallel shelf-faults, but it is well known that this effect of great earthquakes is caused by the incoherence of the soil along the rivers, and has no more tectonical significance than other secondary effects such as landslides, ejections of water and sand, disturbances of springs, etc., all of which were produced also on a great scale at the time of this particular earthquake.

In general it appears that the trapezium has subsided between its northern and southern faults; but, as yet, we cannot be sure that the phenomenon could not result from a rising of the surrounding ground north and south of the bases, the trapezium remaining steady or having been moved also, but with less vertical amplitude; for both geometrical interpretations are equally possible. If we accept the first interpretation we can understand why the intensity decreased suddenly outwards from the basal dislocations; in the last hypothesis the external hilly blocks should have been shaken with the same degrees of intensity, that is to say with an intensity of IX or X,—which did not occur.

Consequently it is ascertained and demonstrated that the seismic movement of November 12, 1912, was a subsidence of the trapezoidal block between its northern and southern faults, which faults were opened at the same time.

In spite of the evidence and certainty deduced from observed phenomena there remains one grave difficulty, for it seems that the ground must necessarily have been broken also in the form of faults along the two oblique sides of the trapezium; but this did not happen. Why it did not occur we do not know; and this impossibility shows us how far we are as yet from knowing the inmost processes of Nature, when a terrestrial block suffers a tectonico-seismic disturbance.

THE EARTHQUAKE OF JANUARY 30, 1917

By Otto Klotz

From the few records received of this earthquake we get a very satisfactory position for the epicenter. The records are pretty accordant as to the respective distances, showing that *P* and *S* have been well marked and well read. The various *O*'s are not quite as accordant, which however, as far as location is concerned, is not material. We have the data from Harvard, Georgetown (Washington), Spring Hill (Mobile), Berkeley and Ottawa as follows:

STATION	*P*	*S*	*L*	*O*	Δ	Ordinate	Vel. per sec. in kms.		
	h m s	h m s	h m s	h m s	km	km	*P*	*S*	*L*
Ottawa	2 56 34	3 05 26	3 13 .4	2 45 43	7440	1057	11.43	6.29	4.48
Harvard	2 56 54	3 06 10	....	2 45 39	7880	1182	11.67	6.40	....
Spring Hill.......	2 57 11	3 06 51	3 21 50	2 45 29	8400	1337	11.96	6.55	3.85
Berkeley	2 54 43	3 02 05	3 07 32	2 45 30	5715	632	10.34	5.74	4.32
Georgetown	2 57 02	3 06 22	3 18 .0	2 45 41	8000	1217	11.75	6.45	4.13

By plotting from the Klotz tables we find the epicentral arcs of Ottawa, Harvard and Georgetown to intersect at a common point while the Berkeley and Spring Hill arcs are slightly off this common point. Taking the weighted point, we find the geographical position of the epicenter to be: $\varphi = 57.0^\circ$ N. $\lambda = 160^\circ\ 10'$ E., that is, in the peninsula of Kamchatka, a well-known seismic and volcanic region. The hearth lies a little to the west of the volcanoes Shiveluch and Kluchevskaya, and the coast town of Nishni Kamchatka.

The region reminds one of Katmai, Alaska, and its eruption and earthquake in June 1912, of which a most interesting account is given in the January number of the *National Geographic Magazine* by Professor Robert F. Griggs. Looking at our 30-inch globe I was struck by the arc running from Katmai along the Aliaska peninsula, along all the Aleutian islands, and close to the above hearth. The arc is of 900 miles radius, and includes an angle of 130°. Its center is a little east of the 180th meridian and at the mouth of the gulf of Anadyr.

It will be observed in the above table, "Velocity per sec. in Kms.," as expected the velocities for the *P* and *S* waves increase with the distance, that is, with the depth along which the ray travels. The *L* or surface waves have theoretically a constant velocity for a homogeneous medium. However, actual records show considerable deviation from a constant value, inferring therefrom want of homogeneity. And this deviation from a constant value has been found from hundreds of records of earthquakes examined here to be greater—far greater—than the deviation of the velocities of *P* and *S* from an average value We conclude that the increase of elasticity and density with depth is far more constant than is the homogeneity of the crust through which the *L* waves are propagated. The writer has in preparation a more extended paper on this subject.

As the peninsula of Kamchatka is of more than ordinary interest to the seismologist, it may be of interest to give the two following quotations, especially as the first is not generally available in libraries.

[1] "Many traces of volcanoes have been observed in this peninsula; and some mountains are still in a burning state. The most considerable of these volcanoes is situated near the village of Ostrog. In 1762 a great noise was heard within the mountains, and flames of fire burst from different parts. These flames were immediately succeeded by a large stream of melted-snow water, which flowed into the neighboring valley, and drowned two Kamtchadals, who were upon a hunting party. The ashes, and other combustible matter, thrown from the mountain, spread to the circumference of two hundred miles. In 1767 there was another discharge, but less considerable. Every night flames were observed issuing from the mountain, and the eruption which attended them, did no small damage to the inhabitants of the Lower Ostrog. Since that year no flames have been seen, but the mountain emits a constant smoke. The same phenomenon was observed upon another mountain, called Tabaetshinski. The volcanoes are, Klutshieffsky, 80 versts[2] from Nishni, up the river Kamtchatka. On the 20th of November, 1789, a great rumbling noise with a smart shock of an earthquake, preceded a violent eruption of small stones, ashes and flames, which continued with daily shocks until the 21st of February, 1790. From information of Captain Billings, the city was illuminated by the flame. The ashes were scattered 800 versts from the mountain, and at half that distance so thickly as to prevent travelling in sledges. August 21st, 1792, about five in the morning, a sudden explosion of large

---

[1] From Coxe's "Russian Discoveries," 1803, pp. 4-7. First edition 1780.

[2] A verst is about ⅝ of a mile, equivalent to about a kilometer.

stones and ashes was immediately followed by a dreadful earthquake, continuing with astonishing violence three-quarters of an hour. It was felt through the whole peninsula, even to Bolcheretsk, where its duration was only a few seconds. All the brick ovens and chimneys were thrown down at Nishni, and the people in consternation crawled over the bed of the river Raduga, which was dry for half an hour, to the mountains.

"Shaevelutsh, a volcano, 80 versts north of Klutshevsky, from which smoke sometimes issues. Tolbatsh, or Tolbatshuisk, 200 versts south of Klutshefskoi constantly emits smoke on the north side near the summit, and along the ridge which seems to unite it to the northern chain. Avatsha or Avatshinsk, 40 versts to the northeastward of the harbor of St. Peter and St. Paul, or Petropaulofski. In 1785 was a violent eruption, and a considerable part of the summit fell in; and in 1799 another covered the neighborhood for many miles with ashes and pumice-stone. Constant smoke issues from the summit, particularly in wet weather. Ozernoi Sopka on the Lopatka, about 60 versts from the south point of the peninsula, began burning in 1792. The neighboring valleys abound in hot springs. Villutsh, called by Cook Paratounka Sopka, is an extinguished volcano. Alaid, a lofty mountain of sugar-loaf form, rising out of the sea, twelve miles west of the south point of Kamtchatka, burnt violently in 1792. Hot springs are found all over the peninsula."

In the Encyclopedia Britannica, eleventh edition, we read:

"The southeastern portion is occupied by a chain of volcanoes, running along the indented coast, from Cape Lopatka to Cape Kronotskiy (54° 25′ N.), and separated from the rest of the peninsula by the valleys of the Bystraya (an affluent of the Bolstraya, on the west coast) and Kamtchatka rivers. Another chain of volcanoes runs from Ichinskaya (which burst into activity several times in the eighteenth and nineteenth centuries) to Shiveluch, seemingly parallel to the above but farther north. The two chains contain twelve active and twenty-six extinct volcanoes, from 7000 to more than 15,000 feet high. The highest volcanoes are grouped under 56° N., and the highest of them, Kluchevskaya (16,990 ft.), is in a state of almost incessant activity (notable outbreaks in 1729, 1737, 1841, 1853-1854, and 1896-1897), a flow of its lava having reached to Kamchatka river in 1853. The active Shiveluch (9900 feet) is the last volcano of this chain. Several lakes and probably Avacha Bay are old craters."

Dominion Observatory, Ottawa,
February 19, 1917.

SEISMOLOGICAL NOTES

S. Thomé, October 16, 1916.—A letter from the Portuguese colony of S. Thomé, dated October 18, 1916, reports an earthquake at that place on October 16(?), 1916, at 3 o'clock p.m. It lasted nearly a minute, but did no damage.

Tejon Pass, California, October 22, 1916.—At 6:45 p.m. October 22, 1916, an earthquake was felt throughout southern California from Fresno on the north to the Imperial Valley on the south. The epicenter seems to have been about the Tejon Pass, near the northwest corner of Los Angeles county. No damage was done. The data collected in regard to it will be given in the next issue of the BULLETIN.

Leonas Valley, California, November 1, 1916.—An earthquake was felt November 1, 1916, at many places in eastern Ventura county and western Los Angeles county, California. Our colleague Mr. Homer Hamlin, of Los Angeles, has kindly gathered and furnished us the following data in regard to it:

The shock occurred between 5 and 5:15 a.m. It was recorded at the following places:

Two miles north of Piru, Ventura county, it lasted about six seconds.

At Bailier, near Quail Lake, the house creaked, and the shock was preceded by a rumbling sound. The location is near the line of the fault through the Tejon Pass. The time given for this observation is 5:15 a.m.

In Frazier mountain, five miles southwest of Tejon Pass, and in Alamo mountain, eleven miles southwest of Gorman, a slight shock lasted two seconds.

At Roosevelt, Los Angeles county, about two miles west of Elizabeth Lake, the shock was preceded by a roar.

At Elizabeth Lake two separate shocks were observed; the first the more severe, rattling doors and windows.

At the Tomson ranch, sixteen miles from Palmdale, a distinct roar was heard, followed by a short shock; another rumbling sound was followed by a second shock. The time is given as 5:15 a.m.

At the Bynum ranch in Bouquet Canyon, seventeen miles from Saugus, the shock is reported at 5:08 a.m., and was preceded by a roaring or grinding sound. This canyon is a sharply defined trench that branches off from the southwest side of Leonas Valley seven miles west of Palmdale.

At Palmdale it was felt by many persons; it was thought to have been more severe south of the fault there than north of it.

At Spillway Camp, in the San Francisquito Canyon, ten or eleven miles north of Saugus, the shock was felt by everyone.

The shock nowhere exceeded an intensity of IV, but its location with reference to an active fault line is especially interesting. The observations available suggest that it originated along the fault that passes through the Tejon Pass and along Pine Canyon, through Elizabeth Lake, Leonas Valley, Anaverde Valley, and about two miles south of the town of Palmdale.

Hemet, California, November 26, 1916.—A shock of low intensity was generally felt at Hemet, Riverside county, California, at 9:10 a.m. of November 26, 1916. It lasted only a few seconds and was accompanied by a low rumbling sound. Some of the inhabitants were alarmed, but no damage was done.

San Luis Obispo, California, December 1, 1916.—Four shocks are reported from San Luis Obispo about 3 p.m. December 1st. The shocks seem to have been heaviest on the coast, where goods were thrown from shelves and glassware was broken. At Avila, eight miles southwest of San Luis Obispo, plaster was broken from the cottages of the Union Oil Company, and some smokestacks were thrown down at the refinery. Landslides are reported in Dairy Canyon.

Verapaz, Guatemala, December 20(?), 1916.—A volcanic explosion is reported to have occurred near the village of Lower Verapaz, and fifteen persons are said to have been killed by it. There is doubt about the date.

Island of Formosa, January 6(?), 1917.—An earthquake in the central part of the island of Formosa is reported to have destroyed a thousand buildings and to have killed three hundred persons. The city of Nanto was also damaged by fire.

Lassen Peak, California, January 15-17, 1917.—At 3:30 p.m. January 15, 1917, Lassen Peak began again to pour forth clouds of dust. On the 17th there was a series of explosions, and dense columns of dust poured from its crater. This was the greatest activity shown by the peak since May 22, 1915.

Bali, Malay Archipelago, January 25(?), 1917.—An earthquake on the island of Bali in the Malay Archipelago on January 25th(?) caused the death of five hundred and fifty persons (official), the injury of three hundred more, and the destruction of more than a thousand buildings. The palace of the governor was seriously damaged. In one village all the houses except fourteen were destroyed by landslides.

Montreal, Canada, January 26, 1917.—An earthquake lasting for fifteen seconds is said to have occurred at Montreal, Canada, the afternoon of January 26, 1917. The shock was felt at Ottawa, where it is said to have lasted four seconds.

Owens Valley, California, February 9, 1917.—Mr. Homer Hamlin, city engineer of Los Angeles, has kindly sent us the following note: "I have received two reports regarding an earthquake which occurred in Owens Valley, February 9, 1917, at 8:30 p.m. It was observed by the keeper at the North Haiwee dam, about four and one-half miles south of Olancha, and also by the keeper of the South Haiwee dam, about twelve miles south of Olancha. The intensity seems to have been about III of the Rossi-Forel scale. A rumbling sound was heard at the North Haiwee dam, but no sounds were noticed by the observer at the South Haiwee dam. It could have passed unnoticed, however, as the wind was blowing hard at the time."

Los Angeles, California, February 13, 1917.—One of our colleagues writes from Los Angeles: "An earthquake occurred here on February 13, 1917, at 5:05 a.m. From incomplete data which I have collected it seems that the epicentrum was about six or eight miles south or southwest of the business district of Los Angeles. The intensity was V or possibly VI of the Rossi-Forel scale at that point.

A report from Saugus states that a shock was felt there by many, having an intensity of IV. The time was reported as 5:10 a.m. I have not found any one between Hollywood and Saugus who felt an earthquake on that date. It may be that these were two distinct shocks."

Fillmore, California, March 29, 1917.—"An earthquake shock of several seconds' duration was felt here at 12:06 this morning. Although it shook buildings and awakened several from their peaceful slumbers, no damage was reported. The temblor must have been only local, as it was not felt in Ventura or in Los Angeles."—*Fillmore Daily Sun,* March 29, 1917. Our colleague Mr. Charles R. Fletcher was at Fillmore at the time, and states that though it did no damage the movement was decidedly sharp. He thinks the quake originated on a fault-line in the mountains near Fillmore.

Stanford University, California, March 29, 1917.—A slight shock was felt by a few persons at 4:59 a.m. on March 29, 1917. It had an intensity of about III, and lasted about two seconds.

Northeastern Victoria, Australia, April 4, 1917.—Telegrams from Australia report an earthquake in towns in northeastern Victoria, but no details are given.

NOTES FROM BRAZIL

We are indebted to our colleague Dr. H. Morize, director of the Observatorio Nacional at Rio de Janeiro, for the following notes on earthquakes in Brazil. One of them occurred several years ago, but the rarity of earthquakes in that country makes it important to record them in the *Bulletin of the Seismological Society.*

Alcantara, Maranhão, December 23, 1909.—An earthquake was felt in the vicinity of Alcantara in the state of Maranhão December 23, 1909. It caused dishes and windows to rattle, but did no damage. The city of Alcantara is on the coast about twenty-seven kilometers northwest of the city of Maranhão.

Morro Velho, Minas.—A slight shock was felt at the Morro Velho gold mines the morning of March 20, 1915. This place is about 150 kilometers southwest of Ouro Preto, state of Minas Geraes.

SEISMOLOGICAL REPORTS RECEIVED

AMERICA

Denver, Colorado. Jesuit Seismological Service, Sacred Heart College.—Reports nos. 10 to 12, and 1 and 2, from October 1, 1916 to February 28, 1917.

La Paz, Bolivia.—Boletin Sismico del Observatorio del Colegio San Calixto (PP. Jesuitas), nos. 39 to 47, from July 17 to September 12, 1916.

Ottawa, Canada. Earthquake Station, Dominion Astronomical Observatory.—Reports nos. 22, 1 and 2, from December 1, 1916 to February 28, 1917.

Washington, D. C.—Seismological Bulletin of the Georgetown University, nos. 21 to 23 bis, from December 1, 1916 to February 28, 1917, and compiled press dispatches for the same period.

ASIA

Zi-Ka-Wei, China.—Bulletin Sismique de l'Observatoire, nos. 19 to 22, from October 21 to December 30, 1916.

Osaka, Japan.—Seismological Bulletin of the Meteorological Observatory from October 1 to December 31, 1916.

EUROPE

Barcelona, Spain.—Estacion Sismica de la Real Academia de Sciences y Artes. Reports 31 to 33, from October 1 to December 31, 1916.

Coimbra, Portugal.—Boletin Sismico do Observatorio da Universidade, nos. 20A to 21A, from October 1 to December 31, 1916.

PHILIPPINE ISLANDS

Manila, P. I.—Seismological Bulletin of the Observatory, nos. 20 to 25, from June 21 to August 31, 1916.

MINUTES OF THE MEETING OF THE BOARD OF DIRECTORS OF THE SEISMOLOGICAL SOCIETY OF AMERICA

January 23, 1917.

In the absence of the president, the meeting was called to order by the secretary, at 4 p.m., in Room 66, Stanford University, California. Directors Branner, Durand and Townley were present, Dr. Branner acting as chairman.

The minutes of the meeting of the Board of Directors on May 17, 1916, were read and approved.

By motions duly made and seconded, the following named persons were elected to membership in the Society:

Wallace W. Atwood, Cambridge, Massachusetts.
Herdman F. Cleland, Williamstown, Massachusetts.
Frederick Ehrenfeld, Philadelphia, Pennsylvania.
C. N. Perry, Calexico, California.
Rohani Thirunal Raja, Travancore, South India.
A. G. Stall, Valdez, Alaska.
George F. White, Valdez, Alaska.
Rex Townsend, Valdez, Alaska.

The secretary announced that the following named institutions had been added to the list of subscribers to the Bulletin of the Society:

Boston Public Library, Boston, Massachusetts.
Free Library of Philadelphia, Philadelphia, Pennsylvania.
Fresno Public Library, Fresno, California.
Geophysical Laboratory, Washington, D. C.
The Grosvenor Library, Buffalo, N. Y.
National Geographic Magazine, Washington, D. C.
Observatorio del Ebro, Tarragona, Spain.
General Library of University of Michigan, Ann Arbor, Mich.
Library of University of Minnesota, Minneapolis, Minn.

The secretary announced the death of the following named members of the Society: Cleveland Abbe, Horace Davis, C. Willard Hayes, and Charles S. Prosser. He also announced the resignation of eight members. The Bureau of Mines of Washington, D. C., was dropped from the list of subscribers; and the name of Rev. Gustavo Heredia, S. J., Pueblo, Mexico, was also dropped, as mail addressed to him had been returned for two years.

Upon motions duly made and seconded, the following committees were appointed:

NOMINATING COMMITTEE	BOARD OF ELECTION
R. S. Holway (chairman)	D. S. Richardson (chairman)
E. F. Davis	Albert Burch
J. A. Taff	F. V. Cornish
Bernard Bienenfeld	R. L. Rowley
A. H. Palmer	H. W. Turner

The secretary announced a gift of $100 from Dr. J. C. Branner, given on September 2, 1916, to help the Society to meet its obligations; and upon motion, the secretary was instructed to convey an expression of appreciation to Dr. Branner.

After considerable discussion, it was decided that the Society should become affiliated with the Pacific Division of the American Association for the Advancement of Science, and that a meeting of the Society should be held at Stanford University in conjunction with the next meeting of the Pacific Division, April 5-7.

The secretary was instructed to write to President Woodworth concerning the matter of affiliation with the American Association for the Advancement of Science itself, in order that meetings might be held in the East in conjunction with the A. A. A. S.

The question of the finances of the Society was discussed at some length, but no official action was taken.

Adjourned at 5 p.m.

S. D. Townley, Secretary.

ROSSI-FOREL SCALE OF EARTHQUAKE INTENSITIES

I. **Microseismic shock**: recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds; the shock felt by an experienced observer.

II. **Extremely feeble shock**: recorded by several seismographs of different kinds; felt by a small number of persons at rest.

III. **Very feeble shock**: felt by several persons at rest; strong enough for the direction or duration to be appreciable.

IV. **Feeble shock**: felt by persons in motion; disturbances of movable objects, doors, windows; creaking of ceilings.

V. **Shock of moderate intensity**: felt generally by everyone; disturbance of furniture, beds, etc., ringing of swinging bells.

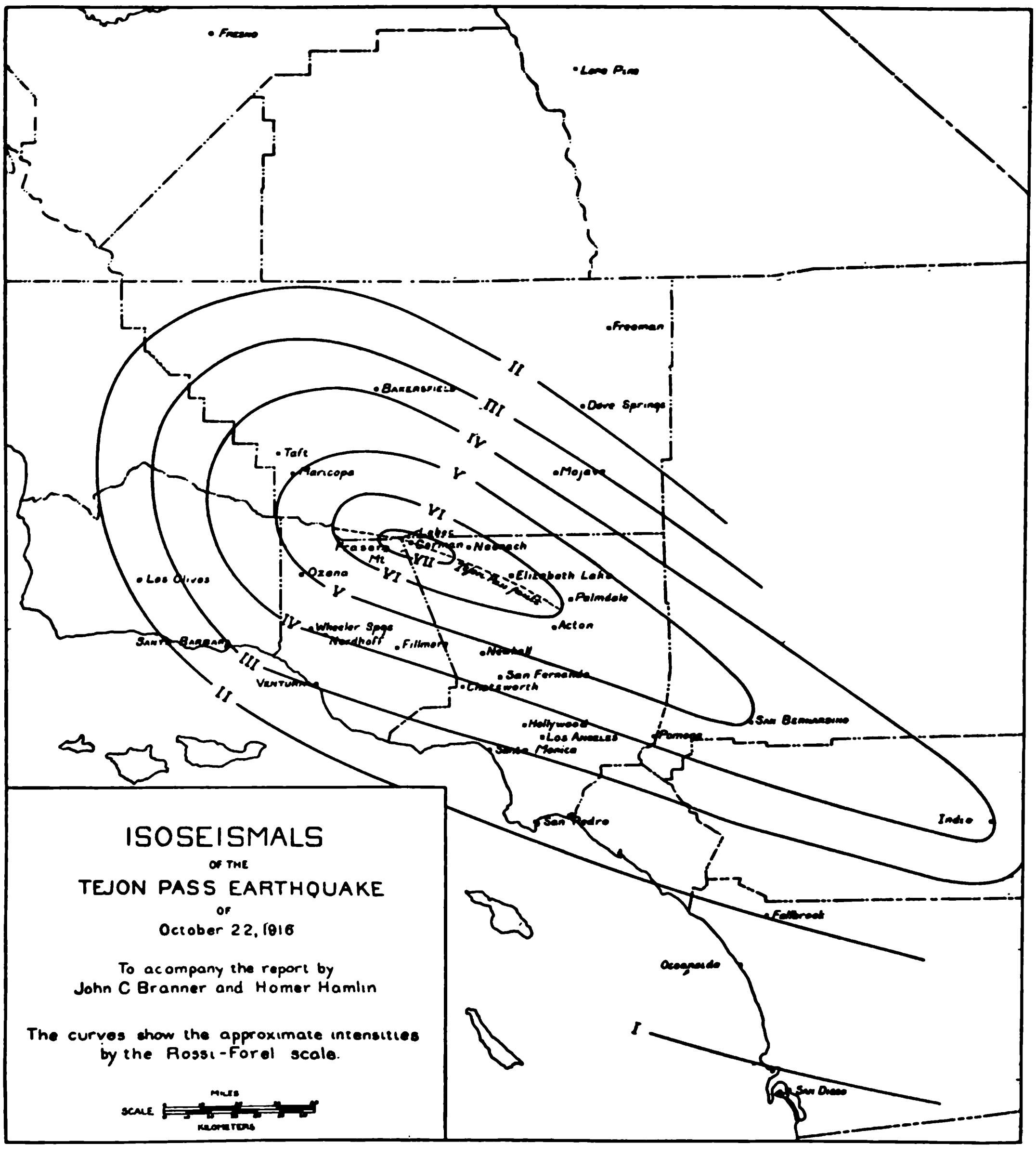
VI. **Fairly strong shock**: general awakening of those asleep; general ringing of house bells; oscillation of chandeliers; stopping of pendulum clocks; visible agitation of trees and shrubs; some startled persons leave their dwellings.

VII. **Strong shock**: overthrow of movable objects; fall of plaster; ringing of church bells; general panic, without damage to buildings.

VIII. **Very strong shock**: fall of chimneys, cracks in walls of buildings.

IX. **Extremely strong shock**: partial or total destruction of some buildings.

X. **Shock of extreme intensity**: great disaster, buildings ruined, disturbance of the strata, fissures in the ground, rock-falls from mountains.



ISOSEISMALS
OF THE
TEJON PASS EARTHQUAKE
OF
October 22, 1916

To acompany the report by
John C Branner and Homer Hamlin

The curves show the approximate intensities
by the Rossi-Forel scale.

The Bulletin of the
Seismological Society of America

VOL. VII. JUNE 1917 No. 2

ONE OF THE SCIENTIFIC PROBLEMS AT OUR DOORS[1]

By JOHN CASPER BRANNER

In earthquakes we have a problem or rather a great group of problems, that nature has left on our very doorsteps. What are we doing with it, and what do we propose to do?

The earthquake of 1906 jolted us into a state of temporary wakefulness, but we seem calmly to have gone asleep again. The only thing to our credit in connection with it is the excellent report of Dr. A. C. Lawson, which stands out, and stands alone, as a contribution to seismology in this country. Very largely through the impetus given to the study of seismology by the earthquake of 1906, the Seismological Society of America was formed here in California in the hope that we might get the cordial support of scientific men and of public-spirited people generally in the study of earthquakes.

Through the patient exertions and personal sacrifices of a handful of men and through the generous contributions of our colleague Mr. Robert W. Sayles, of Harvard University, we have been able to publish six volumes of the society's quarterly bulletin and to get started on a road that seems to lead somewhere.

I am merely stating a fact in connection with this subject when I say that instead of taking hold of the problems of the earthquakes, most of us seem disposed to run from them; or what is still worse, we deny their very existence, while the cöoperation and help we hoped to receive from the public has not been forthcoming. Certain branches of business are especially liable to damage from earthquakes, and it seems quite reasonable that such industries should cöoperate with us by gathering and sending in data regarding earthquakes as they occur. Our railway lines, with their many bridges, cuts and fills, are liable to be seriously damaged and their service interrupted, to say nothing of the possible danger to human life through trains running into dislocations; our telegraph and telephone lines are liable to be broken and their service interrupted; our electric power companies are liable to have their dams injured, their pipe lines and wires broken, and their service seriously interfered with; our water companies are liable to have their dams injured or destroyed, their water mains broken and their service impaired; while our insurance companies are perplexed by rate problems in a region where, in order to protect themselves, they are compelled to make their customers pay for risks about which we are all equally ignorant. As a matter of fact not a single railway or tramway company, not a single telegraph or telephone company, not a single insurance company, not a single electric power company, and only one water company—the Spring Valley Water Company of San Francisco—has ever manifested the slightest interest in our work or lifted a finger to help us gather the data necessary for a rational study of the earthquake problems of this coast. What could we not do if we had the cordial cöoperation of all such organizations on this coast? It seems almost incredible that the business interests of this state and of this coast should willingly and weakly, year after year, allow a permanent threat to hang over their industries, their transportation lines, their public utilities, and their very existence, without making an intelligent effort to study the subject or to help those who are willing and anxious to study it, and to find means of meeting it. Yet such are the sad facts.

---

[1] Part of the presidential address before the Pacific Division of the American Association for the Advancement of Science, at Stanford University, California, April 5, 1917.

What is the explanation of this remarkable state of affairs? So far as I am able to judge, it comes from the false attitude into which the people of this coast have unwittingly drifted. At the time of the earliest settlement of the Pacific coast by whites, pious people grouped the earthquakes along with a choice lot of other disasters and calamities commonly known as "acts of God." And naturally enough pious people regarded the acts of God as things to which we should take off our hats, but which should not be questioned or irreverently pried into.

In time they came to be simply accepted as drawbacks to the general attractiveness of California, and as such it seemed best to regard them as evils to be endured but not to be talked about. Here was a great and beautiful land that lacked capital, a good class of immigrants, and the development of its natural resources; and nothing must be said or done to frighten away either the capital or the immigrants. If the news of an earthquake occasionally made its way out of the state it was immediately given a back seat by being confronted with the enormous damage done by destructive tornadoes and annual floods in the Mississippi Valley. Our real-estate agents rarely or never heard of earthquakes; it seemed better that they should not; such things interfered with business. About the same time the newspapers fell into the habit of forgetting to mention them, and there seemed to grow up spontaneously a sort of conspiracy of silence in regard to the subject. And so it came about that when the earthquake of 1906 broke the water mains of the Spring Valley Water Company and at the same moment set fire to the city of San Francisco, we were entangled in the snares of our own weaving. And now see how we tried to hide our heads in the sand. The geologists hereabouts were very anxious to gather the data made available by that particular earthquake, but as the necessary field work required considerable funds efforts were made to interest some of our business men in the subject. But our business men rose up almost to a man and assured us in the most emphatic language that there had been no earthquake, and we were told to "forget it"; to "cut it out," and above all, to publish no report on it.

It is not necessary to tell this audience that such an attitude is false and absolutely untenable. The battles of science can not be successfully fought with the weapons of ignorance and bigotry.

I am confident that this state of affairs can not long endure. Very likely indeed we have not done our own duty in pointing out what seems to be a rational method in handling the whole matter. But a rational method demands first of all that we face about and get on the right road.

Science knows but one way to deal with its problems, and that is to face them in the open; that is the doctrine to be preached, and to be practiced, and it is the only one.

The more I study earthquakes the more I am convinced that their dangers have been geatly exaggerated by our ignorance and through our efforts to cover them up; and the more am I convinced that a systematic study of the subject on this coast will yet enable us to outline with reasonable precision the areas in which they are liable to be severe, and in this way we may yet do away with their greatest dangers. Such work should eventually enable us to locate dams, bridges and buildings with reference to earthquake risks, and it should enable the insurance companies to deal justly with their customers, and, at the same time, to protect their own legitimate interests.

But such work can not be done in a month or a year, nor yet in ten years. Neither can we depend on the stimulation of violent earthquakes to keep people alive to its importance. Indeed, very little is to be expected of people who require violent stimulants to keep them going. Machinery of that kind generally stops when the stimulants give out. Those who enter this field should be people of some steadfastness of purpose, and who have little or no ambition to pose or dance in the limelights.

It will require years of careful collaboration, of patient gathering of data, of careful study, the mapping of the areas in which the shocks are felt, and the study of the geology in order to know just what is going on, and what is likely to happen.

To those who may think favorably of helping us in our efforts to study earthquakes I should speak this word of warning: Don't expect too much of us, and don't expect it too soon. Science must go its own gait, in its own way, and it often finds itself in a blind alley. It is trying; we wish it were otherwise; but it can not be helped. We can not trust the methods, dogmas or conclusions of authority in science.

Very likely some of you may feel that you do not like to have this or any of these local problems flung at your heads in this brusque fashion. But, my friends, nature has already flung these problems, not only at our heads, but in our very faces. Is it not for us to wake up and be equal to our opportunities? Unless we take hold of the problems of seismology that are so conspicuously our problems here on this coast we shall stand justly discredited in the minds of our colleagues in other parts of the world. The Portuguese have a proverb about people who "fetch water after the house is burned up." Let us see if we can't fetch the water in season.

And while I am using plain language about disagreeable things, I may as well refer to one more unpleasant subject, and have done with it, and that is the necessity of financial backing. Men of science can do the work of science, but they can not foot the bills. For that part of this undertaking we must look to business men. And we look to them with confidence that they will cheerfully do their part. And if we will all pull together and keep up our courage, I feel confident that the day will come when earthquakes will have lost most of their terrors, not only for us on this coast, but for the human race.

PRINCE BORIS GALITZIN

By Otto Klotz

On the 17th of July I received official word from the Imperial Academy of Petrograd of the death on May 17th of Prince Galitzin. It came as a great shock, for he had only reached his fifty-fourth year. My acquaintance with him dates from 1907, when we were both delegates at the first general meeting of the International Seismological Association at The Hague. On a similar occasion we were together for a week at Zermatt in 1909, and again at Manchester in 1911, when he was elected president of that association, and as a compliment to him it was decided that the meeting for 1914 be held in August-September in St. Petersburg, and I was on my way thither when the war stopped further progress. Since 1907 we have been in correspondence with each other on matters pertaining to seismology, that new science of which he became so conspicuous an ornament. As a scientist Galitzin was many-sided, but my personal contact is confined to that of seismology. Like many other cultured Russians he spoke, besides his mother tongue, English, French and German fluently; in fact, his address in English at the Fifth International Congress of Mathematicians at Cambridge in 1912 aroused the admiration of the English for its purity of diction and fluency of delivery.

Galitzin traced his ancestry back to the fourteenth century, being descended from the princes of Lithuania—the Jagello line—which played an important part in the history of Poland. At the time of his death he was a member of the Imperial Academy of Sciences at Petrograd—which in itself shows the eminence he had attained in Russia, and this eminence was international—and President of the Seismological Commission of Russia.

Born at Petrograd on February 18, 1862 (O. S.), Prince Galitzin was brought up at first abroad, and spent the eight years 1880-1887 as a naval officer; he graduated in philosophy at Strasburg in 1890, and became Privatdocent in Moscow, and afterwards professor of physics in Jurjef, before his promotion to Petrograd in 1893. His earlier scientific papers were chiefly on the properties of gases and liquids, and the critical state, but his work covered also other branches of general physics. So early as 1887 he published, with General Rykatcheff, a handbook of meteorology; and later he organized, carried out, and reported upon the observation of clouds and other meteorological and hydrographical observations of the expedition of the Imperial Academy of Sciences to Nova Zembla in 1896.

For the past fifteen years he had thrown his energy and ability into the study of seismology, theoretical and practical. He perfected a seismograph, in which he introduced galvanometric registration, and magnetic damping—a radical innovation in seismographs. His activity is shown by the many papers he published, issued by the Academy and Earthquake Commission, the latter created through his instrumentality. As a result of the latter there have been established throughout the Russian Empire six first-class stations, all provided with his sensitive seismographs, and many second-class stations; so that as far as highly efficient governmental stations are concerned, Russia leads the world—and all due to Galitzin. He was the first to show that with his seismograph not only the distance of an earthquake was obtainable, which is the case, too, with other good instruments, but also the direction within fair limits; so that one instrument practically suffices for the location of an earthquake. The results of his many resarches and studies in seismology were given in a course of eighty-nine lectures at the Imperial Academy, and these were published in a volume, "Seismometrie," in 1911. A German and revised edition was issued by Professor Hecker in 1914, which is one of the most important contributions in the whole literature of seismology. The last communication we had from him was his valuable contribution to the *Comptes Rendus* in 1915, Tome 160, p. 810, being an evaluation of the Pulkowa seismogram in terms of C. G. S. for the Pamir earthquake of February 18, 1911, and of which an account was given in *The Bulletin of the Seismological Society of America,* Vol. V., No. 4, December 1915.

I regret that this brief note is so inadequate and fails to do full justice to Galitzin; at the same time I could not allow the loss to science and particularly to seismology that the death of Galitzin has occasioned to pass in America unnoticed, and hence this record for the *Bulletin.*

Prince Boris Galitzin was a star of the first magnitude.

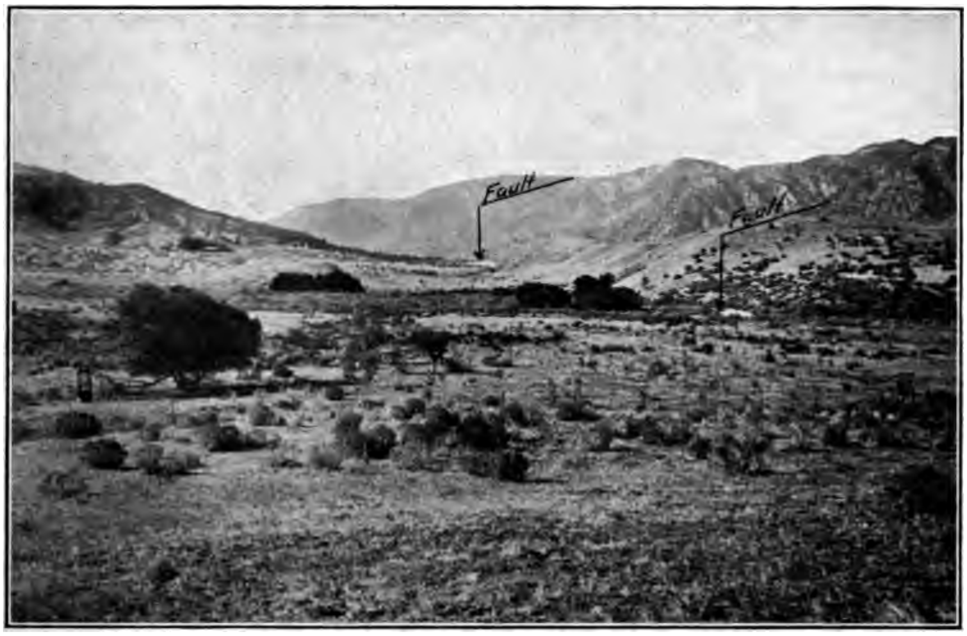


Fig. 1. Fault-scarp in the Tejon Pass, looking north 75° west from a point two and a quarter miles southwest of Lebec.

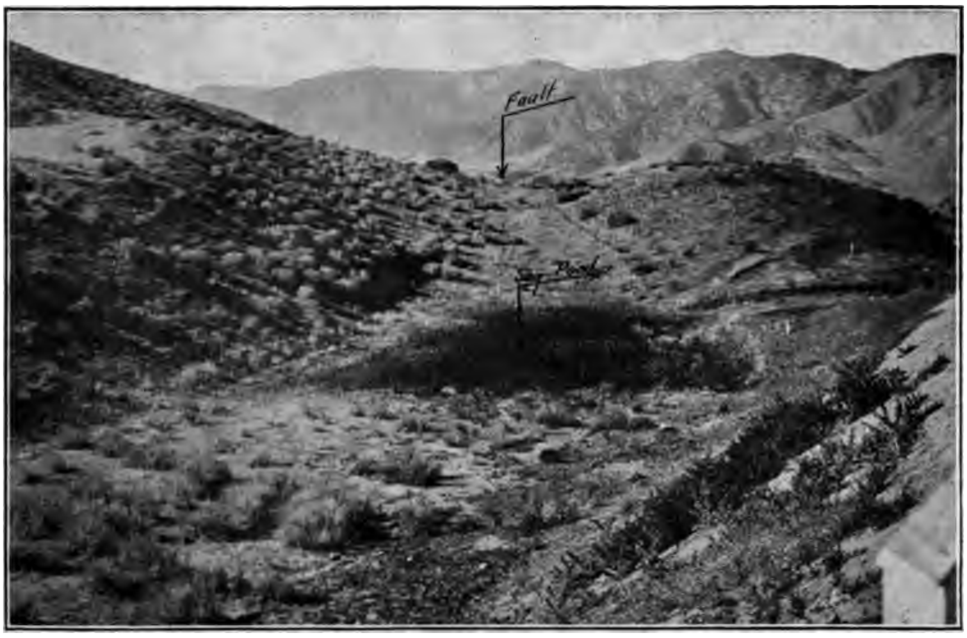


Fig. 2. The fault at the summit of the Tejon Pass; looking west.

THE TEJON PASS EARTHQUAKE OF OCTOBER 22, 1916

By John Casper Branner

Chiefly from data collected by Homer Hamlin,
City Engineer of Los Angeles, California.

The earthquake of October 22, 1916, was the most widely felt and the strongest recorded in California during that year. Data gathered in the field show that its epicenter was at or near the Tejon Pass about the northeast corner of Los Angeles county.

The time of the shock recorded at the Mount Wilson Solar Observatory, near Pasadena, was $6^h 45^m 30^s$ p.m. The observatory is 64 miles south, 53° east of the epicentral region, and this time record is the most southerly one received that can be considered exact.

The station furthest north from which we have a trustworthy record is the seismographic station of the University of California at Berkeley. Mr. E. F. Davis, the assistant in charge, reports the beginning of the shock at $6^h 44^m 46^s$, and that the first shock was interrupted by a second one at $6^h 46^m 31^s$.

The time is reported from many other places, but it is unnecessary to repeat them here; wherever they are mentioned below they must be accepted as the best approximation the observers could give.

The area affected cannot be outlined with certainty for lack of data, but the northernmost points from which it is reported from personal observations are Fresno and Carruthers in Fresno county, 145 miles from the Tejon Pass, while the southernmost point is the city of San Diego, which is 175 miles from the pass. To the west it is reported from Los Olivos, Santa Barbara county, 75 miles west of Tejon Pass; but it was not observed at Freeman, 77 miles to the northeast, or at Dove Springs, 65 miles to the northeast. The best estimate we can make is that it was distinctly felt over an area of 27,000 to 28,000 square miles. No reference is here made to records made by seismographs.

Los Angeles County

Tejon Pass, two miles south of Lebec. At L. O. Chandler's, on the state highway and just south of it, the shock seemed to hit the north side of the building first. The house creaked and rattled, dishes in the cupboard were moved southward against the door; swinging lamps and suspended utensils were set swaying. A total of eight shocks were felt during the night. The first three were preceded by a roaring sound.

Several observers note the starting of loose rocks from hillsides in the mountainous region about the Tejon Pass. Persons who passed over the ridge route from Bakersfield southward the following day reported "a great many rocks in the road said by the road workers to have been shaken down" by the earthquake.

Similar phenomena were observed on Frazier mountain, six miles southwest of Tejon Pass.

GORMAN postoffice and store is in the northwest corner of Los Angeles county, two miles east of Tejon Pass. Here the first shock was felt at 6:40 p.m., and was followed by four other shocks within ten or fifteen minutes. The first one was preceded by a roar, "like a hard wind only louder"; then followed the trembling of the house, the rattling of windows and the clatter of dishes. The inmates started to leave the house when a more violent shock caused the house to sway and creak, threw the dishes from the cupboard and nearly all of the stock of groceries from the shelves in the store, so that it was difficult for a person in the store to get out. Some five minutes later came another shock which threw more goods from the shelves. Mr. J. A. McKenzie states that there were four more shocks, and he reports that a crack opened several hundred feet long and an inch wide in the cement of the state highway which passes the house. After the first five shocks there were no more until about 10 o'clock, when there were eight others between 10 o'clock and daylight the following morning. The second and third shocks were accompanied by noise said to be "fierce, and coming from the north and passing toward the southeast." The store building at Gorman is a low, light, one-story structure, easily shaken. It stands about north-south, the shelves are on the west side of the room and the goods were thrown toward the east.

BAILEY'S is northwest of Quail Lake and near the fault through the Tejon Pass. The first shock felt at this place at 6:45, was preceded by a roar "like an auto truck approaching at high speed." The first shock was the most severe; it rocked the house severely, cracking plaster and rattling dishes. A cupboard started to upset but was caught. The concrete on the state highway at this place is said to have been cracked.

At NEENACH in the Antelope Valley, northwestern part of Los Angeles county, the first shock, preceded by a roar, was at about 6:45 p.m.; the second was lighter, from five to ten minutes later. Houses

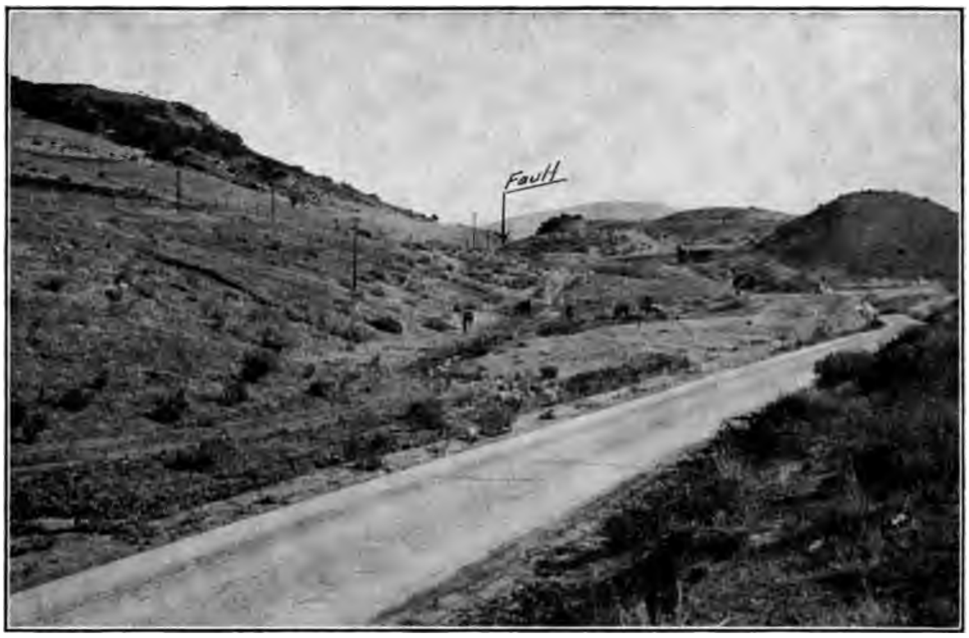


Fig. 3. The fault at the summit of the Tejon Pass; looking east.

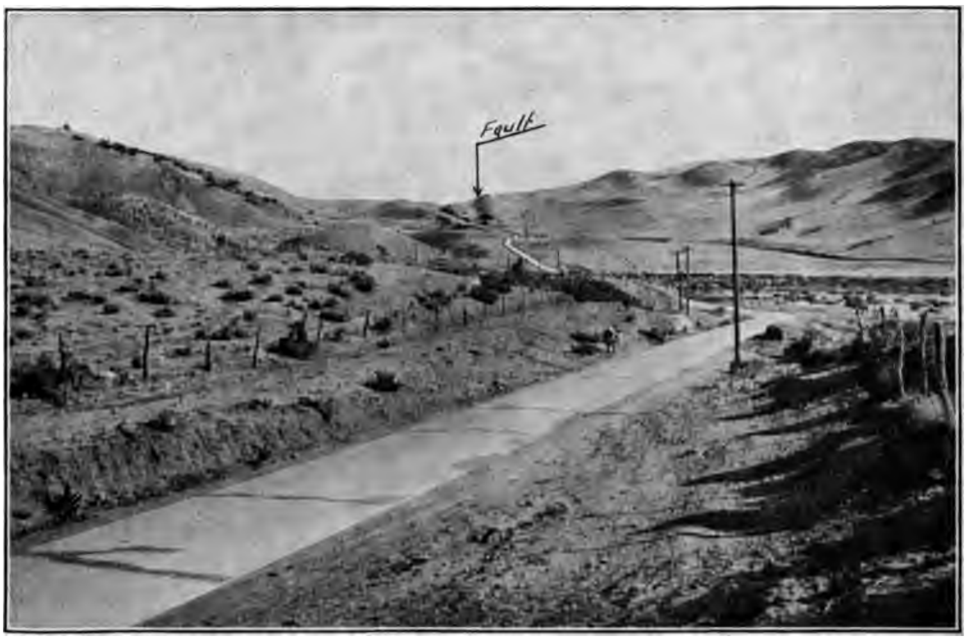


Fig. 4. The fault in the Tejon Pass; looking east from a point half a mile east of German.

creaked, dishes rattled, and furniture was disturbed. A mile east of Neenach the shock seemed to have come from the west. The region is on the alluvial plain near the north base of the mountains.

At MR. GOOKIN'S PLACE on Sec. 36, 8 N., 17 W., which is directly on the fault line between Tejon Pass and Elizabeth Lake, descriptions show that the intensity was about the same as that in the Tejon Pass.

ELIZABETH LAKE, LEONAS VALLEY.—There were two shocks; the first and heavier one was felt by everyone. It was preceded by a rumbling sound. Doors, windows and dishes rattled, and two small packages were thrown from the shelves of a store; bottles were upset and billiard balls moved on a billiard table. Swinging objects vibrated about east-west. At the Munz ranch near Elizabeth Lake, there were three distinct shocks. The disturbance seemed to come from the west and a rumbling sound preceded it. At Roosevelt postoffice a man was nearly thrown down by the shock.

At PALMDALE it was hardly felt.

At FAIRMONT, five miles northwest of Elizabeth Lake, there is said to have been only one light shock, and no sound was observed in connection with it. This place is about four miles from the fault line where it passes through Leonas Valley.

At the FAIRMONT RESERVOIR site, which is about two miles south of Fairmont, and only two and a half miles northeast of the fault through the Leonas valley, three shocks were observed, though the third was hardly noticeable. The shock was generally felt and doors and windows rattled and ceilings creaked.

At ACTON, seven miles south of Anaverde Valley, doors and windows rattled and ceilings and floors creaked. The shock was preceded by a rumbling sound.

On the TOMSON RANCH, near the head of Bouquet Canyon, sixteen miles west of Palmdale, only one shock was observed, which rattled the dishes.

The BYNUM RANCH is in Bouquet Canyon, seventeen miles north of Saugus. At that place a loud roaring was heard just before the first shock was felt at 6:43 p.m. It seemed to come down the canyon from the northwest. It was followed by tremors and then by a hard shake which was followed by tremors again. There was another roaring noise and then a second shock at 6:55 which was not so severe as the first one. Both shocks rattled windows, doors, and dishes.

In the CITY OF LOS ANGELES the time is generally put at 6:45 p.m. with a second shock at 6:55. The shock was not observed by all, but it was generally felt by those at rest, but not by those in motion. In a few instances people ran out of their houses. In some cases dishes were rattled; a baby was awakened from sleep; water in tumblers was visibly disturbed; doors, windows, and window shades rattled in some places; suspended mirrors trembled, hanging lamps swayed; in some instances ceilings and floors creaked; children stopped their play, and one asked "Who is doing that?" Two distinct shocks are generally reported by observers and in some instances three are mentioned. The first shock lasted from two to four seconds or more, and the second one, eight to ten seconds later, was longer, and in one instance the second shock is said to have been more severe than the first; the third was the least violent. Two persons mention a grinding or grating sound like rocks or bricks rubbing against each other.

One observer reports a few rapid vibrations; a door sliding in a wall that runs N. 65° W. rattled slightly, while a similar door in a wall at right angles did not rattle. The shock lasted about ten seconds.

At PASADENA doors and windows rattled in some houses, but in others the shock passed unobserved.

At HOLLYWOOD, northwest of Los Angeles, it was felt by many persons sitting; two shocks were noticed, the second more severe. Doors rattled for two or three seconds; the second shock lasted from five to ten seconds.

At SPILLWAY CAMP, San Francisquito Canyon, ten or eleven miles north of Saugus, the shock was felt by everyone. The tents swayed and doors were thrown open. There were three separate shocks.

At CAMP 3 in the San Francisquito Canyon, about five miles south of Elizabeth Lake, three separate shocks were observed, the first at 6:45. The framed tents rattled and swayed considerably.

At SAUGUS the shock was felt and dishes rattled. A clock keeping standard time pointed to 6:45 p.m. at the time of the shock.

At SANTA MONICA, on the coast, two distinct shocks are reported as generally observed, the first at 6:45 and the second at 6:55 p.m. The second shock is said to have been more severe than the first. Buildings creaked and doors and windows rattled; hanging lamps were set swaying in a northeast-southwest direction.

At CHATSWORTH it was distinctly observed by a few persons.

At NEWHALL the shock was felt by a few persons.

At REDONDO BEACH houses rocked and squeaked; it was noted by all.

At SAN FERNANDO it was felt by many persons; there was no creaking or moving of furniture, but dishes rattled in a frame house.

At SHERMAN it was felt by thirty persons seated; windows rattled; there were two shocks.

At POMONA the local papers mentioned an earthquake but gave no details.

At SAN PEDRO it was not observed by the Harbor Department.

VENTURA COUNTY

On and about FRAZIER MOUNTAIN, six miles southwest of Tejon Pass, the shock loosened rocks from the canyon walls and they rolled down the slopes. On the west side of the mountain near J. D. Cuddy's ranch a crack opened in the ground, and on B. J. Snedden's ranch, in the Lockwood Valley, an adobe house was so badly cracked that it cannot be repaired.

At the FRAZIER BORAX MINE, on the north side of Lockwood Valley, the shock is thought to have been quite as severe or even more severe than in the Tejon Pass. A frame house had its porch detached by the shock.

In the ALAMO MOUNTAIN, eleven miles southwest of the Tejon Pass, the shock was felt at 6:45 p.m. It was preceded by a heavy rumbling. At 6:52 a lighter shock followed, and at 6:57 the heaviest shock occurred and lasted twenty seconds. Limbs fell from the pine trees, and rocks fell from the canyon walls at several places. There was a fourth shock at 7:15 p.m., and a fifth one at 7:30; the last two were barely perceptible. The data regarding Alamo Mountain were furnished by H. H. Hunt, forest ranger, who was camped on the mountain at the time.

At MR. FORD'S PLACE on sections 4 and 9, 7 N., 19 W., a "severe but not heavy shock" was preceded by a roaring noise like a heavy wind. Four distinct shocks were noted, the first two being the heaviest, but not severe enough to throw things off the shelves. Mr. Ford heard rocks roll down a deep narrow gorge.

At the LECHLER RANCH in 5 N. 18 W., section 36, six miles northeast from Piru, three distinct shocks were noticed.

TWO MILES NORTH OF PIRU postoffice the first shock startled people, but it did not appear to affect the oil wells. Three distinct shocks were noted at this place, the first at 6:45, the second at 6:52, and the third at 7:07 p.m.

At FILLMORE it was felt by persons at rest; doors and windows rattled and wooden buildings creaked.

At NORDHOFF two shocks were observed, the first at 6:45 and lasting five seconds; the second at 6:55 and lasting about four seconds.

WHEELER SPRINGS, on the north fork of Matilija Creek, is about thirty miles southwest from the Tejon Pass. The shock was first felt at the springs at about 6:45 p.m.; it lasted about three seconds, and was followed by two others at intervals of about five minutes. The first one startled the guests at the hotel, but no damage was done either there or thereabouts.

At OZENA, twenty-eight miles west-southwest of Tejon Pass, the shock was preceded by a sound "like an automobile coming with the engine working at its best. When the sound reached me it felt as if it came under the ground and under the table at which I sat. It sounded like thunder under the ground as it went by." Four separate shocks were observed at this place; the first and third were accompanied by noise, the second and fourth not so accompanied. The first shock was at 6:47 and lasted about thirty seconds; the second was at 6:48, and lasted ten seconds; the third at 6:52; and the fourth was thirty seconds later and lasted about ten seconds.

KERN COUNTY

In Kern county the shock was generally felt throughout the oil regions of the southern end of the San Joaquin Valley and in the Tehachapi Mountains. Our colleague Mr. Frank Warthorst, to whom we are indebted for valuable data, judges that the intensity at Bakersfield was about IV of the Rossi-Forel scale. At Taft some people rushed from the buildings, but no damage was done. At Maricopa it is reported that an oil well on section 34, 12 S. 24 W., resumed its production after the shock. In the Tehachapi Mountains rocks were shaken down in some of the railway cuts. At Gosford the Santa Fé ticket office, which was in a box-car, was moved along the track four feet by the shock.

CUDDY CANYON.—Inasmuch as the line between Kern county and Ventura and Los Angeles counties is within a mile of Tejon Pass, the epicentral area lies partly in Kern county. Indeed it is the impression of some persons who were in the area at the time of the shock that the highest intensity was in Cuddy Canyon, which drains into Castac Lake from the west and runs along the extreme southern margin of Kern county.

The following account of what happened at the Cuddy house is quoted from a report made by J. O. Marsh to Mr. R. C. Starr under date of November 13, 1916.

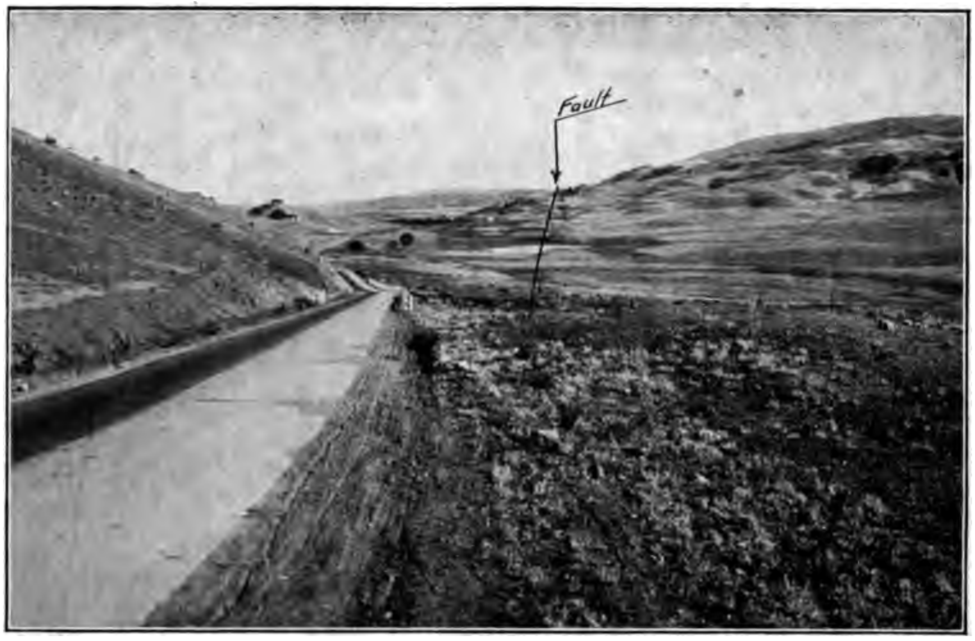
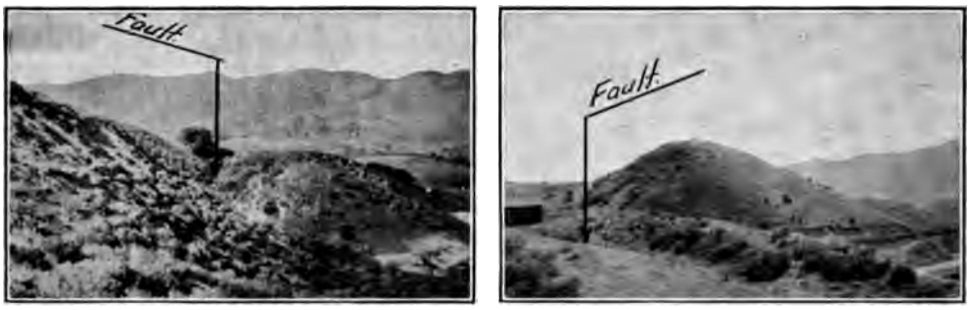
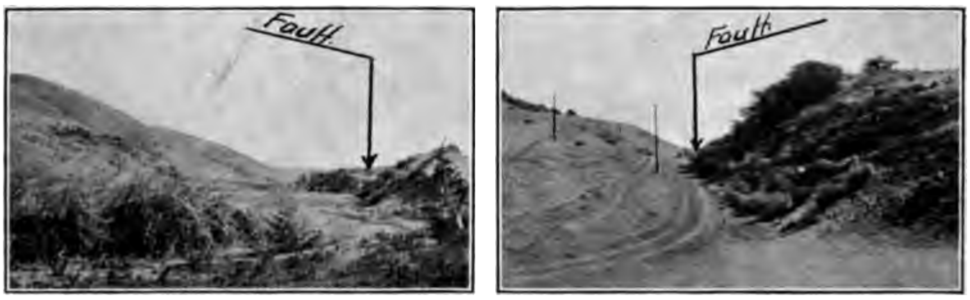


Fig. 5. The fault in the Tejon Pass; looking east from a point two miles east of German.



Fault near the summit of Tejon Pass.

In the fault-zone of Tejon Pass; looking east.



Fault-scarp beside a pond half a mile east of German; looking southeast.

Fault-scarp half a mile east of the summit of Tejon Pass; looking east.

Fig. 6.

"At the old Cuddy homestead in the south branch of the canyon we found the most marked evidences of the earthquake that we discovered on our trip. Here we found a crack along the upper edge of a morass which was from two to six inches wide and about one hundred and fifty feet long, and which did not vary as much as a foot from a straight line. This crack was, for most of its length, on the side of a steep hillside about two to four feet above the level of the morass, but for short distances it was in the bog, where the evidence was destroyed; but the people living there stated that after the quake the crack was continuous. A stone chimney in the house had been cracked, but not seriously. This was the only permanent damage done. Some milk-pans standing on a table on the porch had over half their contents slopped out and across the width of a six-foot porch, but the pans were not disturbed. A woman who was in the house at the time stated that she first heard the roar, and had just decided to go out to investigate when the shock came. Knowing it to be an earthquake she started out. The rocking of the floor was so severe that she paused at the door leading to the porch in order to get her balance, and thought the floor of the porch was rising up towards her, and at this time she observed the milk being thrown from the pans. She then rushed out of the porch door, and seeing the trees swaying about she continued to run in order to escape them if they fell. When she had gone twenty-five feet from the house the shock had passed."

At the R. C. CUDDY RANCH in Cuddy Valley, section 30, 9 N. 20 W., the shock is reported by Mr. J. O. Marsh, in the report quoted, as having been about the same as at the old Cuddy house. Mr. Cuddy had his automobile standing on four jacks at the time, and it was thrown off. Mr. Cuddy thinks the shock was more severe in the San Emigdio Canyon, where a big rock chimney about twelve feet high and used in mining operations had four feet of the top jarred off. He also states that many rocks rolled off the mountains thereabout.

LEBEC, near the Tejon Pass. The first shock was preceded by a roar like a clap of thunder. The house creaked, and loose articles moved. The second shock was preceded by a hissing sound and then by a roar.

At MOJAVE, and at the camp one mile west of there, two light shocks were observed about five minutes apart.

At DOVE SPRINGS, about four miles north of Ricardo, no shock was observed. This place is 65 miles northeast of the Tejon Pass.

In JAWBONE CANYON, 30 S. 37 W., section 19, a point 57 miles northeast of Tejon Pass, two small shocks about five minutes apart were felt by a man sitting in a chair.

RIVERSIDE COUNTY

At RIVERSIDE the shock was felt by many persons, but no details of its intensity are available.

At BEAUMONT the shock was strong enough to be noticed by most persons. It lasted about two seconds.

At INDIO the shock was plainly felt by most people.

In the TEMESCAL QUARRY in Temescal Canyon, four miles southeast of Riverside, it was felt, but no data are available in regard to the intensity there.

In the COACHELLA VALLEY it is said to have been "quite severe," and to have had an up and down movement on section 30, 6 S. 8 E.

SANTA BARBARA COUNTY

At SANTA BARBARA two shocks were observed by a few persons at rest, the first at 6:44 p.m. more severe than the second at 6:55; some clocks were stopped.

At LOS OLIVOS it was felt by a few persons.

SAN DIEGO COUNTY

At SAN DIEGO a very light shock was felt by a few persons.

At JULIAN and FALLBROOK it was felt by several persons at rest.

SAN BERNARDINO COUNTY

It was felt at COLTON by several persons, but no details are available.

At SAN BERNARDINO, as reported to the U. S. Weather Bureau, the patients in the county hospital were badly frightened.

NEGATIVE REPORTS

Reports from the following places say that the shock was *not* observed: Yuma, Arizona; Calexico, Cal., Oceanside, Cal., Descanso and National City, San Diego county, Cal.; Dove Springs, 65 miles northeast of Tejon Pass; Freeman, 77 miles northeast of Tejon Pass; Lone Pine, Inyo county; Crooked Creek Camp on the Los Angeles Aqueduct, and Little Lake on the Los Angeles Aqueduct.

Summary.—The area over which the shock was felt by persons at rest was 27,000 square miles or more, extending from Fresno on the north to San Diego on the south, and from Mojave to the coast.

The epicenter seems to have been near the summit of the Tejon Pass, where the intensity reached VII or a little more, of the Rossi-Forel scale.

At many places the shock was preceded by a pronounced roar like thunder or a high wind. Wherever the direction of the sound was noted it appeared to come from the epicentral area.

The region is too thinly populated and our data are too meager to enable us to outline the area of high intensity with confidence, but the following facts seem to be fairly well established:

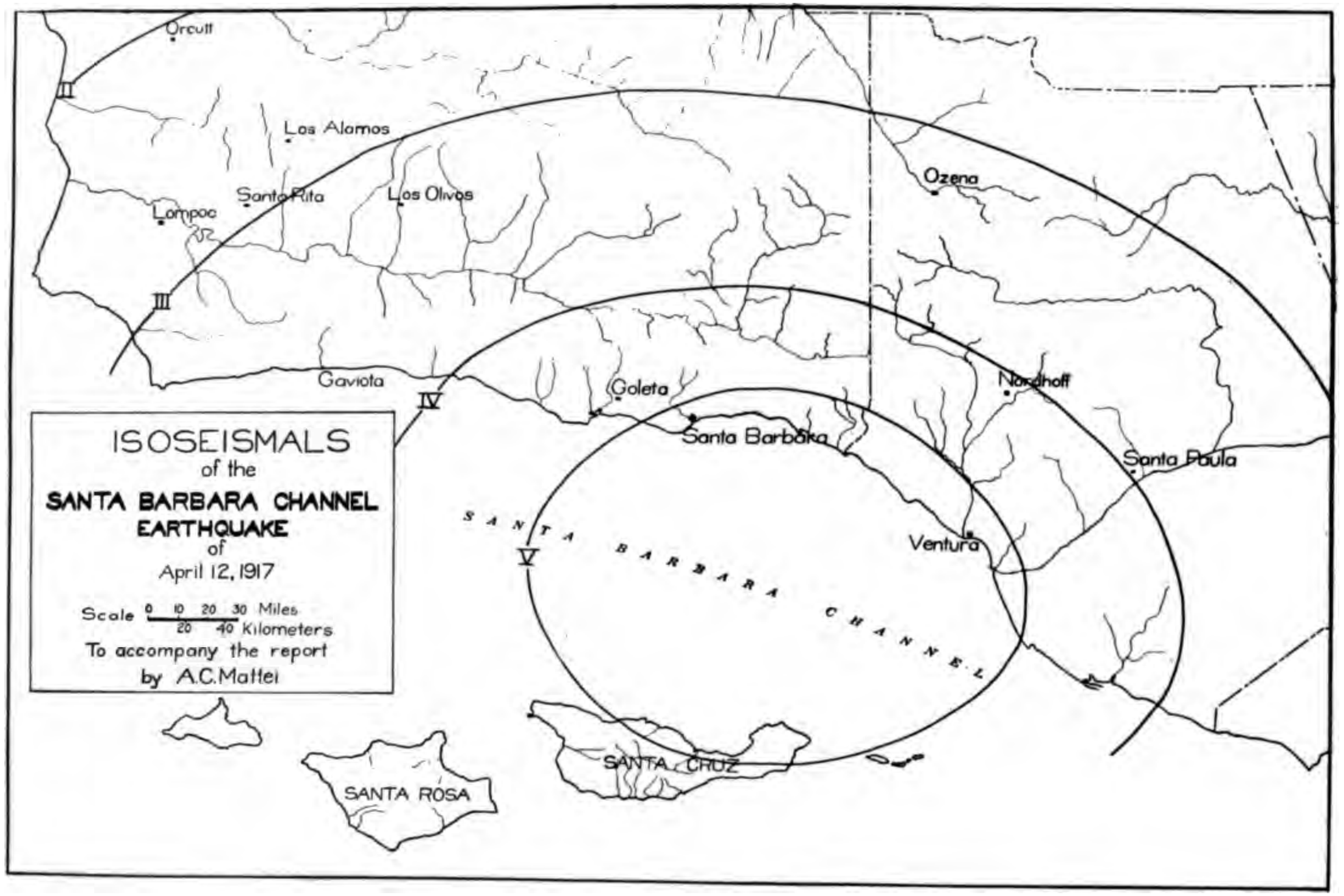
The shock or shocks were produced by movement on the fault line that passes through the Tejon Pass and follows thence east-southeast along the axes of Leonas Valley and Anaverde Valley and northwestward through Cuddy Canyon and Cuddy Valley.

The topographic evidence of the fault in the Tejon Pass is very pronounced, but there is topographic evidence of another fault that branches off from the Tejon Pass fault about a mile and a half northwest of Tejon Pass and runs east-northeast from the northwest corner of Los Angeles county, passing along the north side of Castac Lake. The depression occupied by Castac Lake seems to have been formed by a downthrow on the south side of this fault.

It has been supposed that the fault through Tejon Pass was a southward prolongation of the San Andreas fault near San Francisco. The identity of these faults is far from being evident. The topography, the distribution of earthquake shocks, and the method of fracture along the fault zones all suggest a series of overlapping faults rather than one continuous fault.

Mr. Hamlin says on this subject: "This fault is not a long continuous fracture, but rather a fault zone with numerous branches. Dropped blocks are not uncommon along this zone, some being a mile or more wide and twice as long."

The forms of the isoseismals of this particular earthquake, however, suggest definite relations to this fault zone.



ISOSEISMALS
of the
SANTA BARBARA CHANNEL EARTHQUAKE
of
April 12, 1917

Scale 0 10 20 30 Miles
20 40 Kilometers

To accompany the report
by A.C. Mattei

TWO SANTA BARBARA CHANNEL EARTHQUAKES

By A. C. Mattei

The Earthquake of April 12, 1917

On the evening of April 12, 1917, the region bordering on the Santa Barbara Channel was disturbed by an earthquake that is said to have been the strongest felt in that region since April 1906. The area most affected was along the coast from a few miles west of Santa Barbara to Ventura and reaching back to the Santa Ynez mountains on the north.

A few reports in regard to the shock were sent to the Seismological Society of America, but the bulk of the data was gathered by the writer in the field under the direction of Dr. John C. Branner, and by Mr. Homer Hamlin, city engineer of Los Angeles, who kindly placed at the disposal of the Seismological Society the data collected by him in the area south and east of Santa Barbara. Mr. J. R. Hall, Forest Supervisor of the Santa Barbara Reservation, kindly aided by obtaining information from the forest rangers.

Five days were spent in the field, and, by using an automobile, the region affected was fairly well covered personally. Much of the area is but thinly populated, and it was therefore necessary to communicate with all the people accessible. In a few cases it was impossible to see the people living in certain parts of the area, and personal letters were written to them. The long distance telephone was used to reach some of the more remote ranches that could not be reached otherwise.

On going into the region, the first reports of the earthquake were received at Orcutt, where only a few people at rest felt it. In the region about Los Alamos the intensity was judged to be between II and III of the Rossi-Forel scale. At Los Olivos the shock was also light, and was only felt by people at rest, but it seemed to be felt more generally than at Los Alamos.

As Santa Barbara was approached it was evident that the intensity had grown much stronger. In the city of Santa Barbara three men were on the second floor of a brick building when the shock occurred. The windows in the building rattled violently, and a picture on an easel with a movable frame rattled very perceptibly; but none of the furniture was moved out of place. One man who had gone through the San Francisco earthquake of April 1906 was so frightened that he started to run from the room. The shock was so short that when the man jumped from his seat to rush from the building, he had hardly opened the door of the room when the earthquake ceased. The motion was described as a hard and abrupt shake. All of the people interviewed, except some who were moving about, felt the shock distinctly. No damage was done. The data collected in the city of Santa Barbara indicate an intensity between V and VI of the Rossi-Forel scale.

Along the coast south and east of Santa Barbara as far south as Ventura, the intensity seemed to remain between V and VI. On leaving the coast and going up the Ventura Valley the intensity seemed to be somewhat lower, and at Nordhoff it was placed at about IV. A man standing in a one-story frame house in the town of Nordhoff felt the shock and noticed the door move about six inches. The windows and house rattled and squeaked, but no furniture was moved out of place. Mr. Sherman D. Thacher of the Thacher School at Nordhoff wrote: "I myself was driving an automobile, and did not perceive it. No one at this school spoke of it. One man who was just going into his store at Nordhoff with another man, was met with the inquiry: 'Who is shaking your door?', and as they entered they saw the electric-light fixture swaying five or six inches; it was about three feet long and rather stiff—a somewhat heavy chain interwoven with the cord. Another man in the town reported to me that he and his mother noticed the sound, and had a discussion over whether it was an earthquake or not, he maintaining that it was not and calling attention to the fact that their electric light on the end of a rather long cord (perhaps six feet long) did not sway at all. Another man told me that the shock was very sharp and sudden, as if an animal had bumped up against the house. Another neighbor tells me that they started to leave the house, but the shock was sudden and, not being repeated, they did not get out."

At Wheeler Springs, a few miles north of Nordhoff, the intensity seemed to be somewhat lower—perhaps between III and IV.

In the region of the Casitas Pass, about nine miles west of Nordhoff, the intensity was somewhat higher. At the Davis ranch, in Chismahoo Canyon, a man sitting in a chair was nearly thrown over, and a girl who jumped to grab an oil lamp was thrown off her balance. The windows and house rattled violently. The people living in the vicinity believe the earthquake was more severe than it was in the surrounding country. The intensity at this place seems to have been about V-VI of the Rossi-Forel scale.

Along the foot of the Santa Ynez mountains to the westward the intensity was about the same as at Ventura and Santa Barbara; but north of this range the intensity was found to be much lower. At Ozena the intensity was about III. Here, according to the forest ranger at that station, two shocks were felt, the second following immediately after the first. They were not strong enough to make the house creak, but the windows rattled slightly. Some of the people did not feel the shock at all. At Mono Station, which is across the Santa Ynez mountains directly north of Santa Barbara, the forest ranger states that the shock was one of the strongest felt in that region for many years. The house shook and the windows rattled violently. He was lying down at the time, and noticed a quick jerky motion. It scared the children who were at that time sitting still in the house. The men in the barn, however, did not feel the shock. At the San Marcos ranch house, further down the Santa Ynez river, the shock was not noticed.

Persons traveling to and from the Santa Barbara Islands were consulted, and the information furnished by them and to them by persons living on the islands leads to the conclusion that the earthquake was not only very decidedly felt there, but that the intensity on Santa Cruz was between V and VI. The people on the island of Santa Cruz were seriously alarmed, though no damage seems to have been done.

The time of the shock, as closely as can be determined, was between 7:58 and 7:59 p.m. In Santa Barbara, the time as given by Mr. George W. Russell, weather forecaster, was 7:59 p.m., while Mr. A. B. Cook of Santa Barbara gives it as 7:58. There are no seismographs in the area disturbed.

The duration of the shock was very short. At Montecito a woman jumped from her bed and ran to the door, but by the time she reached the door the movement had ceased. The time indicated must have been between two and three seconds. No place offered any evidence of its lasting more than five seconds, and generally where it was of this reported duration the shock was rather weak. In most instances only one shock was reported.

In the region of the highest intensities sounds accompanied or immediately preceded the shock. At Montecito the majority of the people described the noise as that of muffled thunder, while others in the Casitas Pass region described it as the noise of a "high wind in the pines." One lady living in the mountains near the top of the Casitas Pass said the noise resembled that caused by rocks rolling down the mountain. In Santa Barbara the noise was also heard, and described as that of "steam escaping at a high pressure." In Summerland a "roaring" was very noticeable, and one man describes it as the sound of a fast train going through a tunnel. As a general rule the noise was not heard outside the area of highest intensities.

No damage was done by the earthquake, and, as a rule, the people were not greatly alarmed; such disturbances are not uncommon over a great part of the region.

In the town of Summerland one of the persons interviewed claimed to have felt another very light shock at about 3:00 a.m.; but he was the only one who reported it. No other places reported this shock.

The isoseismal that represents the intensity V of the Rossi-Forel scale, shown on the accompanying map, falls in the region most thickly populated and in which most information was available. The other isoseismals pass through some regions that are very sparsely inhabited.

The isoseismic chart shows that the epicenter of this earthquake was in the Santa Barbara channel.

THE EARTHQUAKE OF APRIL 20, 1917

On April 20, 1917, about 10:59 p.m., another earthquake occurred in the region bordering the Santa Barbara Channel, the shock being generally felt by everyone. The area most affected was the coastal region from Santa Barbara to Ventura, and including the Santa Barbara Islands. This disturbance was felt approximately throughout the same area as the one of April 12, 1917.

At Santa Barbara the intensity was determined to be about V of the Rossi-Forel scale, but the people seemed to think this shock lighter than the one of April 12th. A man in the Elks Club, in the central part of the city, felt the shock and heard the windows rattle and the building creak. The pictures on the walls moved slightly, and water in the glasses moved as if the table had been jarred. Many people were wakened from a sound sleep. About twenty per cent of the people interviewed did not feel the earthquake because they were asleep. In the vicinity of Montecito, about five miles east of Santa Barbara, some of the people thought the shock stronger than the one of April 12th. The bulk of the evidence shows that they were of about the same intensity. One woman was awakened by a "terrific rumbling noise" preceding the shock. As she switched on the electric light she saw the electric cord and globe swing. Another woman near there was so frightened by the shock and noise that she became ill and dizzy. Houses and windows rattled and creaked, and one man heard the rattling of dishes. In the Casitas Pass region the shock is said to have been very similar to that of April 12th. One man was awakened from a sound sleep by the roaring noise which immediately preceded the shock. He felt the swaying motion and then an abrupt bump that caused the dishes to rattle. The house and windows rattled, and his wife, who was sitting up reading, grabbed the lamp which was on the point of being upset. People living a short way down the canyon reported a much lighter shock. The intensity of the shock at this place is estimated at about IV of the Rossi-Forel scale. In the region around Nordhoff, nine miles to the east, the intensity was much lower. Most of the people were asleep at the time of the shock, and only a few were awakened by it. Those who felt the shock gave data which put the intensity for that place between III and IV. In the vicinity of Ventura the intensity was about IV. Many of the people interviewed were not awakened by the shock. Those who did feel it said it was not as strong as the shock of a couple of weeks before. Houses and windows rattled but not so violently as in the shock of April 12th.

At the San Marcos ranch on the Santa Ynez river, about twenty miles northwest of Santa Barbara, the shock awakened most of the people and rattled doors and windows. In the upper Santa Ynez Valley the forest ranger's reports show that the intensity in that area was about III. The people living there were nearly all asleep, and only a few were awakened. The windows rattled, but rather slightly. This earthquake was not felt in the towns of Los Olivos, Los Alamos, Orcutt, Lompoc, Santa Rita, Santa Ynez, or Solvang, and was felt at Gaviota by only a few people, who were in bed but not asleep.

In the Santa Barbara Islands the shock was felt by nearly everyone. Men who were on Santa Cruz Island at that time gave information which shows the intensity there to have been about IV. The men were all asleep and were awakened by the trembling and the rumbling noise. The windows and the house creaked and rattled violently. The motion was rather easy at first, but ended in a very sudden jar, as if the house had been suddenly dropped. No information was received from the other islands, as there are only a few people living on them, and the mail service is not regular.

The time of the shock was about 10:59 p.m. Mr. S. P. Calef of Montecito looked at his watch when he felt the first movement, and it was 10:59 p.m. The people of Santa Barbara state that the city chimes began to ring very shortly after the shock, and they judged the time to have been about 10:59 p.m.

The shock seems to have lasted from three to five seconds. One woman who was awakened by the shock said to her husband: "Robbers are trying to break in," but before she could start a new sentence the movement stopped.

It is generally agreed that the earthquake started with a gentle trembling motion, and at the last it became more severe, and ended in a bumping, jerky motion, generally described as a vertical drop, "as if the house had been dropped and hit on one corner before the rest touched the ground, thus giving a rocking movement, and then settling at the end of the shock." In a few instances two distinct shocks were felt, the first being a trembling, and the next, which came in a second or two, was harder and jerky, as if the house had been bumped by some heavy animal.

Noises of various kinds were described by the people in different parts of the area of highest intensity. On Santa Cruz Island the noise was a "distinct rumbling"; at the San Marcos ranch the noise was described as a "thundering rumble and hissing sound." In Montecito one person described the sound as a "terrific roaring," and another as a "loud moaning." Many people living in the area of the highest intensity did not notice any noise, but others living near described the noise as distinct.

The epicenter of this earthquake seems to have been in the Santa Barbara Channel, and identical with or close to that of the shock of April 12, 1917. The isoseismal IV of the Rossi-Forel scale would pass approximately in the same line as the isoseismal V of the shock of April 12, but would be expanded somewhat. Approximately it would pass through Goleta and well north of Santa Barbara and Ventura, and would include the whole of Santa Cruz Island, and connect up at Goleta with the elongation of the isoseismal running east and west.

VELOCITY OF *L* WAVES

By Otto Klotz

Two years ago the writer examined available earthquake records for determining the velocity of the *L* waves, and in his Seismological Tables published in the beginning of 1916 he used the value of 228 km. per minute, being the mean of the values obtained from 234 earthquakes as recorded at Pulkovo and Ottawa.

Having examined and utilized the records of some 30 stations for the purpose of locating the epicenters for 1916, there was considerable material available for making another determination of the velocity of the *L* waves, and this was done. The modus operandi in brief was as follows: The various records for each earthquake were centered on a sheet or form, appropriately ruled into columns *P, S, L, M, O,* Δ, and others; the latter do not now concern us. Where *P* and *S* were given, Δ could be taken from the Seismological Tables, and from the Δ each *O* could be found. A glance at the sheet after these entries were made would indicate any glaring inconsistencies either in the Δ or *O* column. Then, by means of the stereographic projection, the epicenter or its probable position was found, and expressed in geographic co-ordinates. Next, on a 30-inch globe were measured the distances from the epicenter to each station that had any record. From the various *O*'s a weighted mean was adopted for each earthquake, and this *O* was taken as the G.M.T. of the happening of the shock. Where there was no obvious clock error at any station, the letter *O* was subtracted from the time of the *L* wave at any particular station, and the measured or improved Δ used as the actual distance; this, divided by the time interval, *L–O,* gave the velocity of the *L* waves for that station and for the earthquake under consideration. This proceeding was pursued for all the data available for 1916, and with the result shown in the Table, on the following page.

Total No. of values = 347, Total Sum of values = 80,112 km.; hence average value = 231 km. Taking the average of the various stations, we have: No. of stations = 30, Sum station values = 6910 km.; hence average value = 230 km. The preceding value has necessarily the greater weight, although the two values are almost identical.

Remembering that our previous value is 228 km. per minute, already referred to, we can with considerable confidence adopt 230 km.

STATION	No. of Values	Sum of Values	Average Value per Minute
Ottawa	36	8359	232
Cheltenham	11	2482	224
Harvard	21	4980	237
Georgetown	21	4793	228
Washington	34	7868	231
Tucson	4	837	209
Honolulu	21	4935	235
Vieques	6	1386	231
Balboa	8	1813	227
Sitka	7	1594	228
La Paz	26	5750	221
Eskdalemuir	13	3072	236
Coimbra	18	4248	236
Barcelona	12	2832	236
Zikawei	8	1873	234
Osaka	17	4080	240
Batavia	6	1367	228
Sydney	6	1473	245
Cartuja	11	2573	234
Algiers	23	5351	233
Berkeley	5	1157	231
Manila	5	1074	215
Victoria	3	705	235
Lawrence	2	461	230
Tiflis	3	673	224
Paris	2	494	247
Saskatoon	6	1387	231
Spring Hill	1	217	217
Northfield	7	1532	219
Ithaca	4	946	236
Totals	347	80,112	

per minute as the average and uniform velocity of the *L* waves. Applying this value to one's seismogram, it may frequently prevent erroneous and impossible readings or interpretations of *L* or *L R* waves. What we mean is, if for instance $S\text{–}P = 10$ min., then it is impossible for the *L* waves to follow within 10 minutes after *S*.

The velocities have been arranged too for distances, taking the even thousand, 1000, 2000, 3000, 4000 up to 19,000; and, as expected, the velocity is shown not to be a function of the distance, as is the case with *P* and *S* waves. The mean values for the different 1000 km. distances are not the same, but vary with no regularity. The greatest range we have is between the 3000 km. distance and the 9000 km. one. The former gives 217 km., and is mostly obtained from the three stations, Washington, Georgetown, Cheltenham, which are practically coincident; while the latter gives 244 km., and is dependent principally upon Eskdalemuir, Coimbra, Barcelona and Algiers. It happens that the mean of these two values is also the value of our general mean. The mean of the 19 means for the distances 1000 to 19,000 km. is 232 km. per minute. It will be observed that in the various combinations for obtaining a mean value, *i. e.*, a general mean from all the values 347, or the mean taken by the 30 stations, or the mean when arranged by 19 distances, give values 231, 230, 232 km. respectively. It is scarcely necessary to observe that if we admit that the exact moment of beginning of *L* is subject to an uncertainty, this uncertainty will have a greater effect on the deduced velocity for shorter distances than for greater distances.

To repeat, from the 234 earthquakes for Pulkovo and Ottawa we had 468 values, and above we have 347 values (together 817 determinations), giving 228, 231, 230, and 232 km. Hence in adopting for the velocity of the *L* or surface waves 230 km. per minute, we feel confident that still more extended data will confine any change in this value within one per cent.

To this brief note on the velocity of *L* waves a few other observations may be added, and they are given in a kindly spirit. Every seismological station should make its records, that is, the readings of the seismograms, available at the earliest possible time to other seismologists; for a station not issuing or publishing its records is lost to the scientific world, and its labors are of little value. Progress can only be made by co-operation, and this is essentially true in seismology. The preferable method is to issue monthly bulletins, say within a fortnight after the expiration of the immediately preceding month, as is done by several stations. If the expense prohibits such, the results could be sent to the Weather Bureau at Washington, which would publish them in the *Monthly Review* for the respective month. This is urged even for stations that publish annual or semi-annual records, for it is found that these latter are often issued half a year after the last earthquake recorded,—which means a year after the first one. This is not quite fair to investigators who are desirous of utilizing all data. To receive valuable data after long computations and deductions have been made does not further a true Christian spirit. By all means let us publish our readings at the earliest possible time. So much for getting out early reports.

An improvement is sorely needed too in the time. Every observer should strive to have his recording clock correct within a second. With available wireless signals from Arlington, and the telegraph service, there seems no reason why the time records should not be reliable—which they are not now for all stations.

A word about the reading of seismograms.—The interpretation of *P* and *S* is sometimes very simple, within a second or so; but often this is not the case. The beginning of *L* is never so sharply defined as is the case with *i P*; in fact *L* is at times difficult to locate,—that is, its beginning,—although subsequent beautiful sinusoidal waves show up. Still we can prevent impossibilities of interpretation. The Seismological Tables are not perfect,—we all want to perfect them,—yet they are sufficiently accurate to ensure consistent readings within pretty narrow limits; and this point may perhaps be emphasized with reference to interpretation of seismograms. When a pretty fair reading is obtained for P and S, and hence the distance Δ obtained, we are sometimes enabled to detect $P\ R_1$: by taking half the distance, finding the corresponding time from the origin, and doubling this, we have the time interval from the time O; and this added to the latter gives us the time where $P\ R_1$ is to be expected on the seismogram. And so for $S\ R_1$; but this latter is more likely to be masked in the medley of preceding waves. Of course outstanding differences in period between P and L waves distinguish them readily. Sometimes where the breakdown is not sudden, but consists of successive breakdowns, we find a P wave (of very short period) superposed on L waves, and by means of the preceding S–P line may find a second S. Or the P may be uncertain although the S and L are well marked. From L–S we obtain a fair value of Δ, and hence from the Tables we find S–P; and this applied to S shows us approximately where to look for P. Frequently this leads to a definite reading for P. The relative positions on a seismogram of P, S, and L are given by the Tables, which materially assist in reading and interpreting a seismogram accurately and consistently. A seismogram is a complicated handwriting, frequently difficult to decipher. But we must remember that the seismogram—and the seismogram alone—is the key to unlock the secrets of the interior of the earth. The geodesist is doing valiant service with his sounding-rod of about 120 km. in length, but his investigations are confined to a shallow sea and its density, variable though it be. The seismologist sounds, or attempts to sound, to the very center of the earth, and puts to the seismogram questions not only about velocity, about density, but about elasticity, rigidity, and compressibility. Seismology offers a tempting field to the geophysicists. The present world catastrophe has deprived us of many valuable European records; however we should be able with our American records to deal satisfactorily with many earthquakes, provided the readings are fairly good interpretations. Fortunately Zi-ka-wei, Osaka, Manila and Batavia belong to the stations that still issue monthly bulletins, and hence are particularly valuable for data of the large seismic area that is near them. It may be pointed out that when our time, our readings, our interpretations are more accurate the field of investigation will increase, and problems in geophysics can be attacked which now must remain in abeyance for want of material of sufficient reliability. To mention one of these problems: At present epicenters are located on the assumption that the earthquake issued from a point, which we know is not the case. It is probable that we have at times submarine adjustments along some fault-line of great extent, like the San Andreas one of California. It is not unreasonable to believe that with high-class seismographs and expert readings of their records we would not only be able to obtain the average position of the epicenter but also the position and direction of the fault-line itself; not that this latter has a great value *per se,* but that improved velocity values would result, and from these then the various constants—such as those of density, elasticity, rigidity, compressibility—of the material along the paths of the seismic rays. The interior of the earth would become an open book. That open book can only be based on reliable data, towards which we all can contribute.

An ideal situation would be attained if some government office, preferably one in Washington, were to make seismology an earnest branch of investigation and research; an office to which all our American records would be sent to be digested; an office that would freely and frankly criticise the records of any station, looking to their improvement; an office presided over by a competent geophysicist and supported by able assistants. There is already a mass of undigested material on hand at the various stations, of which perhaps the greatest inherent defect is that of clock correction. But hereafter can we not expect good time records on our seismograms, can we not look to well-adjusted seismographs with known constants, and can we not improve our reading or interpretation of the handwriting of that messenger who brings us so valuable and interesting news of his route? I can picture to myself that within a few years such a rich harvest will be garnered that the process of threshing and winnowing the golden grain will be a pleasure. Some fifty years ago Huxley said that "the grandest mill will not extract wheat flour from peas-cods, so pages of formulæ will not get a definite result out of loose data." Let us beware of loose data.

Dominion Observatory, Ottawa,
May 1, 1917.

SEISMOLOGICAL NOTES

Bishop, California, March 21, 1917.—On March 21, 1917, an earthquake shock was felt at Bishop, California, in the Owens Valley, and in the region to the northwest of that place. It occurred at about 9:10 a.m. In Bishop the intensity was probably III to IV. There was but one bumping jar at this point, which began abruptly. At the Crooked Creek Camp of the Los Angeles Power Bureau, twenty-four miles northwest of Bishop, two shocks, each of about fifteen seconds duration, were felt. These shocks were noticeable in the tunnel which is being driven at that point. Reports are conflicting regarding the intensity of the shock in the mountains west of Bishop. Some observers say the shock was light, others say it was hard enough to dislodge rocks on the mountain side. The shock was not noticed at Laws or at Benton, nor, so far as is now known, to the south of Bishop.—HOMER HAMLIN.

Santa Rita, California, April 5, 1917.—The region around Santa Rita, in west central Santa Barbara county, was disturbed by a slight earthquake on April 5, 1917, at about 11:00 a.m. The shock does not seem to have been felt outside of the Lompoc Valley. The region of highest intensity was in the town of Santa Rita, where it was generally felt. The intensity of the shock is believed to have been between III and IV of the Rossi-Forel scale. In the village a woman walking by the side of her house felt the shock, which made the windows and house rattle and creak. Another woman in an old house about half a mile from there said the pans hanging against the wall of the house rattled, and one or two were shaken down; the house creaked and rattled and the windows seemed as if they were going to break. The house was old and in bad condition, but it was not damaged by the shock.

The shock was felt in the town of Lompoc, eight miles west of Santa Rita, by a few people at rest, but it was not felt generally at Lompoc. One man described it as a slight tremor, which did not rattle windows or creak houses in that particular vicinity. A woman living about three miles north of the town of Lompoc felt the earthquake as she was sewing, and said that the house and windows rattled slightly, but her husband, who was in the yard, did not feel it. Two or three lighter shocks were felt in the same vicinity during the month of April, but they were also local.—A. C. MATTEI.

Missouri, April 9, 1917.— A sharp earthquake was felt in the region lying between St. Louis and Ironton, Missouri, at 2:53 p.m. on April 9th. Information received by the U. S. Weather Bureau shows that over an area of about three thousand square miles the intensity reached VI of the Rossi-Forel scale.

Father Brickel, S. J., of St. Louis University, has kindly furnished the following information in regard to it:

> On April 9, 1917, St. Louis and the surrounding region was shaken by an earthquake lasting from 2:52 p.m. till 3:00 p.m. My attention was called to the shock by the motion of objects in my room, When I arrived at the instrument-room perceptible tremors had died away. An inspection of the seismogram yielded no accurate periods and amplitudes, for, as is well known, horizontally-recording seismographs give badly blurred records for local shocks.
>
> From many parts of the city and its suburbs reports were telephoned to the observatory. According to these serious damage had been done nowhere. The falling of several men, horses, windows and street-lamps, the dislocation of pictures, plaster and chimneys, the rushing of people from buildings, seemed to be the most striking phenomena.
>
> At 5:36 p.m. another earthquake of less intensity than the first was recorded. It was perceived by many.
>
> From telegraphic reports to the press and from correspondence with the observatory, the meizoseismic area seems to have been the region lying within more than a hundred miles radius of St. Louis, although perceptible shocks were felt in five states, Iowa, Indiana, Illinois, Wisconsin and Missouri. The farthest points north were: Prairie du Chien, Wis., and neighborhood; south, Sikeston, Mo.; west, Kansas City, Mo.; east, Central Indiana. The area of greater disturbance was about 465 miles from north to south, and about 440 miles from east to west.
>
> Geomorphogenic manifestations, which might lead to determination of the origin of the earthquake, have not been discovered.
>
> Any connection of this earthquake with the origin of the well-known New Madrid, Mo., earthquake area does not as yet seem probable.
>
> The Rossi-Forel scale would characterize this earthquake as IV: that of the Göttingen scale, IId.

Santa Barbara–Ventura, California, April 12, 1917.— About eight p.m. April 12th, an earthquake was felt in the region along the coast from west of Santa Barbara to Oxnard in Ventura county. The intensity seems to have been about IV of the Rossi-Forel scale.

Rochester, Nevada, April 15, 1917.— A light shock with an intensity of III R.-F. scale was felt at Rochester and Lovelock, Nevada, April 15, 1917, at 10:30 a.m.

Calexico, California, April 18, 1917.— Our colleague C. N. Perry, of Calexico has kindly sent a note of a light shock observed at that place at 3:47 p.m. on April 18th. It was generally felt, and is judged to have had an intensity of III of the Rossi-Forel scale.

Umbria, Italy, April 26, 1917.— Telegrams from Rome report a violent earthquake in Umbria and Tuscany, April 26th. It is stated that many persons were killed, that Citerna was almost completely wrecked, and that the village of Monterchi was destroyed. On the 30th more shocks were reported.

Calexico, California, May 17, 1917.— On May 17th a shock was felt at Calexico, California, at 10:08 p.m. It was preceded by underground rumbling resembling that of a muffled explosion. There was but one short shock, that lasted only about a second, and had an intensity of about IV, R.-F. scale.

Ogdensburg, New York, May 22, 1917.— Three earthquake shocks are reported from the vicinity of Ogdensburg, N. Y., at 4 a.m. May 22d. No damage was done.

Needles, California, May 24, 1917.— A slight shock was felt at Needles, Cal., May 24, 1917, at 2 p.m. It was also felt at Palo Verde, Cal. The shock was so light that it was observed by only a few persons.

Yuma, Arizona, May 27, 1917.— A shock was felt at Yuma, Arizona, at 7 p.m. on May 27th. The shock was not generally felt, and is reported as "simply a distinct jar" strong enough to cause suspended lights to sway.

Imperial Valley, California, May 27, 1917.— An earthquake occurred in the Imperial Valley, May 27th, at 10:06 p.m. It was generally felt throughout the region between the Colorado River at Palo Verde and the coast region at San Diego. It seems to have been the heaviest shock felt in southern California since that of October 22, 1916. Data are being collected in regard to it, and we hope to be able to give a fuller account later. There was no damage, but at Brawley, where closing exercises were being held at the Sacred Heart Catholic School, the rocking of the building came near causing a serious panic.

Cahuilla, California, June 1, 1917.— Dr. Wm. L. Shank of Cahuilla reports that an earthquake was felt there on June 1st, at 8:35 p.m. The place is near the San Jacinto fault-zone and about thirty-three miles east of Hemet, Cal. The intensity is believed to have been between IV and V.

Victorville, California, June 2, 1917.— About 6:30 a.m. on June 2, 1917, an earthquake was felt at Victorville, Cal. The intensity was apparently about III of the R.-F. scale. This shock was not reported from Barstow or Hesperia.

Power-House site No. 2, June 5, 1917.— At Power-House site No. 2 in San Francisquito Canyon twelve miles northeast from Saugus, Cal., a light shock was felt between 9 and 10 p.m., with an intensity of III, R.-F. scale.

Caliexico, California, June 7, 1917.— At 7:41 a.m. on June 7th an earthquake was felt at Calexico, Cal. There was but one shock lasting about two seconds and preceded by faint underground sounds. It had an intensity of IV, R.-F. scale.

Calexico, California, June 7, 1917.— At 4:31 p.m. on June 7th a sharp shock was felt at Calexico, Cal. It was a single shock with an intensity of IV, R.-F. scale, and lasting only two seconds. The shock was reported by C. N. Perry and P. V. Hanf. From Palo Verde on the Colorado River, A. P. Wiley reported a shock on the same day at

4:35. At 10:13 p.m. of the same day Mr. Perry felt another shock at Calexico, Cal.

San Salvador, Salvador, June 7, 1917.— Press dispatches tell of violent earthquakes at San Salvador, Central America, beginning at 7 p.m. on June 7th and lasting through the night. The reports received are somewhat conflicting, but it seems evident that many persons were killed and injured, and a large number of houses destroyed. The shocks are said to have been almost continuous for more than five hours. Fire broke out in the city, but the water-supply seems to have been destroyed, and the fire could not be extinguished. Heavy rains, however, are said to have fallen for six hours. The San Salvador volcano in the vicinity threw out ashes, covering the surrounding country. On the 8th and 9th the earthquake shocks continued to be felt in the region, but of diminishing intensity. Several of the smaller towns and villages in the vicinity suffered greatly, notably La Libertad. Thousands of persons are said to have been rendered homeless by the earthquake. On June 14th shocks were again reported, but without further damage.

Terni, Italy, June 11, 1917.—Press dispatches dated Rome, June 11th, report four violent earthquakes and considerable damage at Terni, Italy.

Heber, California, June 17, 1917.— An earthquake was felt at Heber, Cal., in the Imperial Valley, on June 17, 1917, between 10 and 11 p.m. The shock was preceded by a faint underground rumbling, began abruptly with a bumping motion, and faded off into a tremble. It is reported to have been generally felt, to have jarred buildings, rattled doors and windows, and caused creaking of ceilings, etc. The intensity was probably about V.

Calexico, California, June 18, 1917.— At 1:55 a.m. an earthquake was felt at Calexico. It was preceded by faint underground noises, and the shock consisted of an abrupt bump with an intensity of IV, R.-F. scale. (Mr. Best and Mr. Hanf.) A very light shock with an intensity of III was felt at Calexico at 6:21 p.m. (Mr. Perry.)

REVIEW

THE GREAT ERUPTION OF SAKURA-JIMA IN 1914. By Professor Bunjiro Kotô, Ph. D., Professor of Geology, Science College, Imperial University of Tokyo. With 24 plates and 49 text-figures. *Journal College of Science, Imperial University of Tokyo.* Published by the University, December 25, 1916. Vol. XXXVIII, Art. 3, pp. 237.

Two noteworthy reports have been published with commendable promptness on the great eruption of Sakura-jima on January 12, 1914, one by Professor Omori, the other by his colleague, Professor Kotô. The present notice relates to the latter work.

The eruption of this Japanese volcano is described as not only unusual in its magnitude but also in its copious discharge of lavas issuing from vents on opposite sides of the volcanic pile. In part I of the report the author presents a general outline of the geological structure of southwest Japan. Between Kyusyu, the southern of the three islands of "Old Japan," and Taiwan, over 6½ degrees of latitude to the southward, there stretches the arc of the Ryu-Kyu isles, considered by Kotô to be the geographic and geologic homologue of the Lesser Antilles, having the same triple division into an outer zone of Tertiary and post-Tertiary formations, a middle zone of palæozoic rocks, and an inner zone of recent or active volcanic vents. Sakura-jima is a member of this series of vents, lying within the outline of the island of Kyusyu, where the "Peri-Tunghai tectonic line," beginning in Taiwan and following the Ryu-Kyu arc, intersects that island in its passage northward into the fault bounding the eastern coast of Corea. The Ryu-Kyu arc is monoclinal in structure, dipping westward, with its uptilted overthrust edge facing the Ryu-Kyu graben (7000 m.) on the open Pacific. To the deployment of the overthrust rocks, Kotô ascribes the arcuate alignment of submarine mountain structure whose crests form the Ryu-Kyu isles. A reactionary regressive collapse on the continental side gave rise to the Asiatic shallow bank, and later to the outburst of magma along the inner volcanic zone. The Peri-Tunghai dislocation occurred between the Cretaceous period and the pre-Lepidocyclina Tertiary epoch. Faulting and vertical movement took place in the later Tertiary, and movement is still in progress.

The volcanic activity and the formation of the trench bay of Kagoshima began as a concomitant of this later movement. Sakura-jima rises out of the wedged-in bottom of a rift-valley produced in these changes of structure. In regard to this position of the vent, Kotô posits that volcanoes find their orifices only on the edge of a rift-valley when the depressed and compressed crustal block is underthrust against the standing block, which thereby is caused to rise and burst open, so as to permit the escape of the magma through it. In the case of Sakura-jima, the lavas escaped upward through the fractures of the dropped block which created Kagoshima Bay.

It is not permissible in this place to abstract the details which the distinguished Japanese geologist has studiously correlated with the location of the volcano and neighboring vents of former activity. The volcano of Sakura-jima rises within the narrow trench of Kagoshima Bay, 3.7 kms. east of the city of the same name, to a height (prior to the eruption) of 1333 meters. The coastal skirt of talus and wash supported nineteen villages and a farming and fishing population of 27,116 people. On the island grows the gigantic Japanese radish nearly twenty inches in diameter. Sakura-jima had three summit craters in nearly ventral position arranged approximately north and south, of which the main crater was on the north, the southern craters being successively newer and parasitic in origin. [A manifestation of what the reviewer would term equatorward progression of vents under planetary controls: compare motion of sun-spots.]

Eruptions of Sakura-jima are said to have begun in 708 A.D., and the islands according to the ancient records arose in a single night. For seven centuries no eruptions are mentioned until the period covered by the years 1468-1476. Activity was renewed in 1642, 1678, 1706, 1742, 1749, 1756 (hot springs only); terrible eruptions set in in 1779, lasting into 1781.

On November 7, 1779, Kagoshima was violently shaken. From 10 a.m. to noon on the 8th the water in all the wells of Sakura-jima boiled up, spouting at several places. The eruption from the south crater set in about 2 p.m. Many changes appeared in the vicinity of the volcano, including new islands, regarded by Kotô as the accumulation about submarine vents over a magma reservoir of satellitic injection, the liberated gases of which ate away the roof, giving rise to the submarine outpourings. This period of eruptivity continued spasmodically until 1799. Aside from some minor hot-spring action and flames reported from the south crater in the winter of 1878 and again in the spring of 1879, Sakura-jima remained quiescent until the eruption of 1914. Kotô counts the eruption of this year as the seventh in the history of the volcano.

Premonitory signs of the eruption of 1914 occurred as early as the spring of 1913, when the hot-springs of Kurokami on the eastern coast of Sakura-jima ceased to flow, and when somewhat later certain alkaline hot-springs on the south shore became too hot for bathing during low tides. Quakings and detonations from the 19th to the 30th of May, especially on the 22d and 23d of May, in the hollow 55 km. north of Kagoshima, gave the inhabitants some anxiety. On the 29th and 30th of June the disturbances commenced 15 km. west of the city, where clocks were stopped and some houses were damaged by earth-shocks. On November 8th, December 9th, and January 8th (1914), the volcano Kirishima, 55 km. north from Sakura-jima, ejected ashes in successive explosions. A week prior to the culminating episode of the 12th of January, a small pond on Sakura-jima became dry; and on the 8th thick snow fell in the Bay, a rare event in warm southern Kyushu.

From the morning of January 10th precursory shocks in the vicinity of the vent became increasingly frequent and more intense. Masses of rock began to slide on the mountain, setting up dust clouds simulating explosions. Up to 10 a.m. on the 12th, 418 shocks were recorded. At 7:15 p.m. on the 11th cannonading sounds were heard for the first time. People began to leave Kagoshima on the 11th, and those who remained spent a restless night.

On the morn of the fateful day the quakings diminished somewhat between 1 and 3 a.m., reviving afterwards until noon. The strongest shock was felt at 5:30 a.m. At about 8 a.m., after an earthquake, white clouds rose over the west slope facing Kagoshima; and at 9:10 a.m. white steam clouds rose straight up from the southern top-crater. After an interval of five minutes, an earthquake accompanied by cannonading sounds and tremblings ushered in an eruption from the western vent, while red glares announced the issuance of lava. The eastern vent went into action a little later.

The action on the west side rose quickly to a maximum by 10:40 a.m. Coarse ejectamenta and ash were thrown up to a height of 18,181 meters. At noon the earthquakes abated, owing, as Kotô states, to the release of the pent-up gases which opened a way for the lavas to the surface. At 2:30 black-ash smoke enveloped the whole island; and at 3:30 p.m. explosions began on a grand scale. Lava began to flow down just before a violent earthquake at 6:29 p.m.

Thus the explosive phase ended and that of the true eruption began. Similar activities took place on the east side. These detailed abstracts must suffice as an illustration of the actual records of events in the opening phases of the eruption. The flows of lava and the details of their petrographic characters pertain more to volcanology than to seismology, which is concerned with volcanic earthquakes. Our author gives many details from his diary concerning the after-shocks up to the time of writing. We must now turn to some of his conclusions.

First, Kotô states that the eruption at Sakura-jima was not an accidental explosion of pent-up steam and gases near the old crater pit of a slumbering volcano: the cause lay far and deep, in an epirogenic movement responding to the varying conditions of stress-accumulation in the interior or to the gliding of the outer shell over the nucleus. He adopts the view of Jensen (*in re* Samoa) that a volcanic island revives its activity after a cycle of sixty years; adding that regional activity of deep origin revives after the double length of about sixty years, *i. e.*, after the lapse of one hundred and twenty to one hundred and thirty-five years in the cases cited.

In generalizing concerning the earth-shocks, Kotô notes the shift of epicenters from west to east, the occurrence of the daily maximum of frequency of shocks two hours later than the arrival of the tropical hour of maximum atmospheric pressure, corroborating the long recognized rule in Japan that high pressure determines the moment of quaking, and also of vulcanism. The local pressure maxima occurred from 8 to 10 a.m., and 8 to 11 p.m.; the maxima of earthquake frequency from 8 to 9 a.m., and from 8 to 9 p.m. Kotô quotes Omori as estimating the volume of ejecta during the eruptions to have been 0.62 cub. km., a subject intimately associated with the subsidence of the environs of Sakura-jima.

Kotô found through the resurvey of the area by the Ordnance Department that subsidence had taken place and continues within a radius of 61 kms. of the central tract off the northern shore of Sakura-jima. Kotô discusses the bearing of the measured displacement upon the hypothesis of isostacy. He concludes with Ampferer (1906) that the hot mobile, middle layer or undercurrent was forced up under hydrostatic pressure through the vents of Sakura-jima in the form of lava, and that the cold heavy crust sank down to compensate the mass defect, producing on the surface a kettle-shaped depression; at the same time there was a horizontal shift of the ground towards the center of the deformed tract.

Many other instructive observations and explanatory remarks are made in this unusually complete report. A series of beautiful illustrations, sketches, and a colored geological map of Sakura-jima supplement the lucid text.

J. B. WOODWORTH.

HARVARD SEISMOGRAPHIC STATION,
CAMBRIDGE, MASS., May 9, 1917.

SEISMOLOGICAL REPORTS RECEIVED

AMERICA

Denver, Colorado.— Jesuit Seismological Service, Sacred Heart College. Reports nos. 3 and 4, from March 1 to April 30, 1917.

Harvard University, Cambridge, Mass.— Record of the Seismographic Station, from March 3 to March 26, 1917.

La Paz, Bolivia.— Boletin Sismico del Observatorio del Colegio San Calixto (P. P. Jesuitas), nos. 48 to 54, from September 12 to November 24, 1916.

Ottawa, Canada.— Earthquake Station, Dominion Astronomical Observatory. Reports nos. 3 and 4, from March 1 to April 30, 1917.

Washington, D. C.— Seismological Bulletin of the Georgetown University, nos. 24 to 25, from March 1 to April 30, 1917. From the same station compiled press dispatches during the same period.

ASIA

Zi-Ka-Wei, China.— Bulletin Sismique de l'Observatoire, nos. 1 and 2, from January 4 to January 30, 1917; also Supplement no. 1 for the same period.

Osaka, Japan.— Seismological Bulletin of the Meteorological Observatory from January 4 to February 20, 1917.

EUROPE

Barcelona, Spain.— Estacion Sismica de la Real Academia de Sciences y Artes. Reports 34 to 36, from January 4 to March 31, 1917.

Coimbra, Portugal.— Boletim Sismico do Observatorio da Universidade, nos. 1 and 1*A*, from January 1 to February 28, 1917.

Stonyhurst College, England.— Earthquake Records of the Observatory, from September 2, 1916, to March 29, 1917.

PHILIPPINE ISLANDS

Manila, P. I.— Seismological Bulletin of the Observatory, nos. 26 to 32, from September 1 to October 31, 1916.

We have received the first five numbers of the *Boletin Mensual of the Oficina Meteorologica Nacional* of the Argentine Republic, published at Buenos Aires from January to May, 1916. While the bulk of these reports is taken up with weather, rainfall, height of the principal streams, temperatures, etc., they also contain reports of the seismographic station at Pilar, where two Milne instruments are installed, and of the one at Mendoza, where there is a Bosch-Omori seismograph.

MINUTES OF THE MEETING OF THE SEISMOLOGICAL SOCIETY OF AMERICA

April 7, 1917

The meeting was called to order by Vice-President Tolman at 9 a.m. in Room 334, Stanford University, California.

The reading of the minutes of the last meeting of the Society, on August 4 and 5, 1915, was omitted.

The following program of papers was presented:—

"The Earthquake Problem in the Western United States," by H. O. Wood, Hawaiian Volcano Observatory, Volcano House, Hawaii. (Presented by Bailey Willis.)

"The Earthquake of January 30, 1917," by Otto Klotz, Ottawa, Canada. (Presented by S. D. Townley.)

"Note on the Earthquakes at Almirante, Republic of Panama, in April 1916," by H. F. Reid, Johns Hopkins University, Baltimore, Maryland. (Presented by S. D. Townley.)

"A New Liquid Damping Contrivance for Seismographs," by A. Lemos, National Observatory, Rio de Janeiro, Brazil. (Presented by S. D. Townley.)

"Earthquakes in California in 1916," by A. H. Palmer, United States Weather Bureau, San Francisco, Cal. (Presented by S. D. Townley.)

"The Mexican Earthquake of November 12, 1912," by Count de Montessus de Ballore, Santiago, Chile. (Presented by J. C. Branner.)

"The Tejon Pass Earthquake of October 22, 1916," by J. C. Branner, Stanford University, and Homer Hamlin, Los Angeles. (Presented by J. C. Branner.)

S. D. Townley, *Secretary.*

MINUTES OF THE MEETING OF THE BOARD OF DIRECTORS OF THE SEISMOLOGICAL SOCIETY OF AMERICA

May 16, 1917

In the absence of the President, the meeting was called to order by Vice-President Tolman, at 3 p.m., in Room 66, Stanford University, California. Directors Branner, Campbell, Tolman, and Townley were present.

The minutes of the meeting of the Board of Directors of January 23, 1917, were read and approved.

The report of the Board of Election was read by the Secretary, and ordered filed.

After being duly nominated, the following officers were elected for the year:

President	J. B. Woodworth
First Vice-President	C. F. Tolman, Jr.
Second Vice-President	Ralph Arnold
Third Vice-President	C. F. Marvin
Secretary-Treasurer	S. D. Townley

The report of the Secretary-Treasurer for the year ending April 7, 1917, was read, and ordered filed.

The report of the Auditing Committee was read by the Secretary, and ordered filed.

Upon motions duly made and seconded, the following named persons were elected to membership in the Society:

Board of Fire Underwriters of the Pacific; San Francisco, California. (Life member.)

Commercial Union Assurance Company, Limited: San Francisco, California. (Life member.)

J. J. Beeson: Alta, Utah.
J. H. Branscomb: Butte, Montana.
W. S. DuVal: San Francisco, California.
J. A. Gunn, Jr.: Kelseyville, California.
Geo. V. Lawry: Salt Lake City, Utah.
Thomas McCaughern: San Francisco, California.
Jas. N. McCune: Portland, Oregon.
C. W. Mitchell: San Francisco, California.
G. M. Robertson: San Francisco, California.
A. H. Scott: Lovelock, Nevada.
B. J. Smith: Oakland, California.
Sam B. Stoy: San Francisco, California.
C. F. Wagner: Portland, Oregon.
Richard Waldron, Jr.: Los Angeles, California.
Rolla V. Watt: San Francisco, California.
Bailey Willis: Stanford University, California.

Mr. John T. Fogarty of San Francisco, and the Astrophysical Observatory of the Smithsonian Institution, of Washington, were added to the list of subscribers.

The Secretary reported the resignation of W. C. Repetti, S. J., and Warren D. Smith, and the dropping of six members for the non-payment of dues.

The Secretary reported on the matter of affiliation of the Society with the American Association for the Advancement of Science, and was instructed to proceed with arrangements for affiliation.

Dr. Branner pointed out the desirability of having a fund upon which the directors of the Society could draw in order to make field investigations of earthquakes occurring in the Pacific Coast Region. After considerable discussion it was decided, by a motion duly made and seconded, to ask the Pacific Division of the American Association for the Advancement of Science to provide funds for the purpose just mentioned, and Directors Campbell and Townley were appointed a committee to attend to the necessary correspondence.

A gift of $67.65 for the investigation of the earthquake near Santa Barbara on April 12, 1917, was received from Dr. Branner, and acknowledged with appreciation by the other directors.

A letter from Mr. Chas. R. Fletcher suggesting that the dues of the Society be increased and that the status of Fellow of the Society be established, was read by the Secretary. The matter was discussed at some length, but no official action was taken.

The salary of the Secretary-Treasurer was continued for one year at the rate of $20 per month.

Adjourned at 4:15.

S. D. Townley, *Secretary.*

REPORT OF THE BOARD OF ELECTION OF THE SEISMOLOGICAL SOCIETY OF AMERICA

San Francisco, California, April 7, 1917.

Dr. S. D. Townley,
Secretary Seismological Society of America,
Stanford University, California.

Dear Sir:

The undersigned, constituting the Board of Election of the Seismological Society of America to conduct the elections of this date for a Board of Directors for said Society, hereby certify that the elections were held in due form in Room 752 of the Phelan Building, San Francisco, between the hours of 1 and 3 p.m. of April 7, 1917.

The total number of ballots cast was 116.

The *twelve* candidates receiving the largest number of votes were the following:

NAME OF CANDIDATE	VOTE	NAME OF CANDIDATE	VOTE
J. C. Branner Stanford University, Cal.	112	Ralph Arnold Los Angeles, Cal.	86
S. D. Townley Stanford University, Cal.	106	J. B. Woodworth Cambridge, Mass.	85
A. C. Lawson Berkeley, Cal.	101	A. G. McAdie Readville, Mass.	83
W. W. Campbell Mt. Hamilton, Cal.	96	H. F. Reid Baltimore, Md.	82
C. F. Marvin Washington, D. C.	92	H. O. Wood Volcano House, Hawaii	80
C. F. Tolman, Jr. Stanford University, Cal.	89	W. F. Durand Stanford University, Cal.	74

We therefore declare the above named persons to be duly elected as the Board of Directors of the Seismological Society of America for the ensuing year.

H. W. Turner,
D. S. Richardson,
Board of Election.

The vote for the other candidates was as follows:

NAME OF CANDIDATE	VOTE	NAME OF CANDIDATE	VOTE
W. H. Hobbs	62	J. K. Moffitt	48
J. A. Taff	60	Wm. Mulholland	41
Otto Klotz	59	J. C. Cebrian	27

(Note added by the *Editor.*)

REPORT OF SECRETARY-TREASURER

From April 1, 1916, to April 7, 1917

The total number of members of the Society and subscribers to the BULLETIN is now 408, a decrease of two during the year. Five members were lost thru death: Cleveland Abbe, Washington, D. C.; Horace Davis, San Francisco, Cal.; C. Willard Hays, Tampico, Mexico; Joseph A. Holmes, Washington, D. C.; Charles S. Prosser, Columbus, Ohio.

Volume 6 of the BULLETIN, containing 255 pages and ten plates, was issued during 1916.

The financial report is as follows:

GENERAL FUND

Dr.	
To balance, April 1, 1916	$ 111.31
Dues and subscriptions	663.70
Reprints	57.70
Sale of publications	121.00
Gift from J. C. Branner	100.00
Transfer from Sayles Fund, interest	247.06
Transfer from Sayles Fund, principal	175.00
Transfer from Life Membership Fund, interest	19.35
Gift from J. C. Branner	8.15
Total	$1,503.27
Cr.	
By Stanford University Press, printing Vol. 6	$ 907.65
Stanford University Press, reprints	88.85
Stanford University Press, miscellaneous printing	30.25
Commercial Art Co., illustrations	12.48
Sunset Publishing House, illustrations	35.10
Second-class postage on BULLETINS	7.78
Foreign postage on BULLETINS	9.40
Miscellaneous postage	8.49
Stamped envelopes	42.48
Cablegram	3.06
Pacific Division, A. A. A. S.	5.00
Express	0.25
Rent safety deposit box	2.00
Drawings	8.15
Salary of Secretary-Treasurer	240.00
Balance	102.33
Total	$1,503.27

LIFE MEMBERSHIP FUND

Dr.	
To balance, April 1, 1916	$ 450.00
Three life memberships	75.00
Interest from Berkeley Bank of Savings and Trust Co.	19.35
Total	$ 544.35
Cr.	
By interest, transferred to General Fund	$ 19.35
Balance, April 7, 1917	525.00
Total	$ 544.35

SAYLES FUND

Dr.	
To balance, April 1, 1916	$4,175.00
Interest from Mutual Building and Loan Association of San Jose and College Park	60.00
Interest from Palo Alto Mutual Building and Loan Association	120.00
Interest from Truckee Lumber Co.	60.00
Interest from Bank of Palo Alto, Savings Department	7.06
Total	$4,422.06
Cr.	
By transfer to General Fund, interest	$ 247.06
Transfer to General Fund, principal	175.00
Balance, April 7, 1917	4,000.00
Total	$4,422.06

S. D. TOWNLEY, *Secretary-Treasurer.*

AUDIT OF THE SEISMOLOGICAL SOCIETY OF AMERICA

April 1st, 1916, to April 7th, 1917

GENERAL FUND

Balance April 7, 1917	$102.33

Vouchers submitted, properly receipted, for each payment made by Secretary-Treasurer.

Dues and other cash receipts, properly posted to the account.

The balance, $102.33, is on deposit with the Bank of Palo Alto. Bank statement, showing the above amount on deposit, submitted to Auditing Committee.

LIFE MEMBERSHIP FUND

Balance, April 7, 1917	$525.00

This amount is on deposit in the Berkeley Bank of Savings, Berkeley, California. It represents a balance of $450.00 on hand at the beginning of the fiscal year and three new life memberships at $25.00 each. The interest earned upon the account during the fiscal year was $19.35, which amount was transferred to the General Fund.

SAYLES FUND

Condition as follows, April 7, 1917:

Certificate No. 158, Palo Alto Building and Loan Association	$1,000.00
Certificate No. 159, Palo Alto Building and Loan Association	1,000.00
Certificate Mutual Building and Loan Association, San Jose	1,000.00
(The above are 6% certificates. Interest collected and transferred to General Fund.)	
Truckee Lumber Company first mortgage 6% gold bond	1,000.00
(Interest collected and transferred to General Fund.)	
Total	$4,000.00

($175.00 formerly deposited in Palo Alto Savings Bank and part of this fund, transferred to General Fund during fiscal year. The above described Certificates of Stock and the bond have not been seen by Auditing Committee. Reported deposited in Safe Deposit, Palo Alto.)

RECAPITULATION

General Fund	$ 102.33
Life Membership Fund	525.00
Sayles Fund	4,000.00
Total	$4,627.33

J. K. MOFFITT,
OTTO VON GELDERN,
Auditing Committee.

ROSSI-FOREL SCALE OF EARTHQUAKE INTENSITIES

I. **Microseismic shock**: recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds; the shock felt by an experienced observer.

II. **Extremely feeble shock**: recorded by several seismographs of different kinds; felt by a small number of persons at rest.

III. **Very feeble shock**: felt by several persons at rest; strong enough for the direction or duration to be appreciable.

IV. **Feeble shock**: felt by persons in motion; disturbances of movable objects, doors, windows; creaking of ceilings.

V. **Shock of moderate intensity**: felt generally by everyone; disturbance of furniture, beds, etc., ringing of swinging bells.

VI. **Fairly strong shock**: general awakening of those asleep; general ringing of house bells; oscillation of chandeliers; stopping of pendulum clocks; visible agitation of trees and shrubs; some startled persons leave their dwellings.

VII. **Strong shock**: overthrow of movable objects; fall of plaster; ringing of church bells; general panic, without damage to buildings.

VIII. **Very strong shock**: fall of chimneys, cracks in walls of buildings.

IX. **Extremely strong shock**: partial or total destruction of some buildings.

X. **Shock of extreme intensity**: great disaster, buildings ruined, disturbance of the strata, fissures in the ground, rock-falls from mountains.

The Bulletin of the
Seismological Society of America

VOL. VII. SEPTEMBER, 1917. NO. 3

THE MISSOURI EARTHQUAKE OF APRIL 9, 1917

By RUY H. FINCH, Assistant, U. S. Weather Bureau

On the 9th of April, 1917, a little before 3 p. m., central time, an earthquake occurred near the middle of the eastern border of Missouri that was felt in 10 different States. It was felt over most of Missouri and Illinois, and at many places in Iowa, Wisconsin, Indiana, Kentucky, Tennessee, Mississippi, Arkansas, and Kansas. At first it was thought that the earthquake had its origin in the New Madrid region, but later reports indicate that the epicenter was somewhere between there and St. Louis.

Most of the information relative to this earthquake was obtained from some 160 question cards filled out by co-operative observers of the Weather Bureau—postmasters and others—most of whom rendered these reports shortly after the occurrence of the shock while its effects were still fresh in their minds. The majority of the accounts thus received are given in some detail in Table 1, their intensities and geographical distribution are shown on the accompanying isoseismal map, figure 1.

As was recently pointed out by Montessus de Ballore,[1] the use of isoseismals drawn from estimates of intensities that at best are bound to be at variance is unsatisfactory. Nevertheless such isoseismals give a better idea of the relative distribution of intensities than would be had if omitted.

The area over which this earthquake was felt, elliptical in shape, extends about 600 miles in a north-south direction and over 500 miles east-west, covering approximately 200,000 square miles. In addition to being both felt and instrumentally recorded at St. Louis University, St. Louis, Mo., and the University of Kansas, Lawrence, Kans., slight records were also obtained at St. Ignatius College, Cleveland, Ohio, about 520 miles away, and the Weather Bureau, Washington, D. C., about 760 miles away from the epicentral region.

The beginning of the disturbance as given by the majority of observers was $2^h\ 52^m$— $2^h\ 53^m$ p. m. (central time). The time at origin as calculated from the seismograph record of the University of Kan-

---

[1] *Bulletin Seismological Society of America.* **6**, 227.

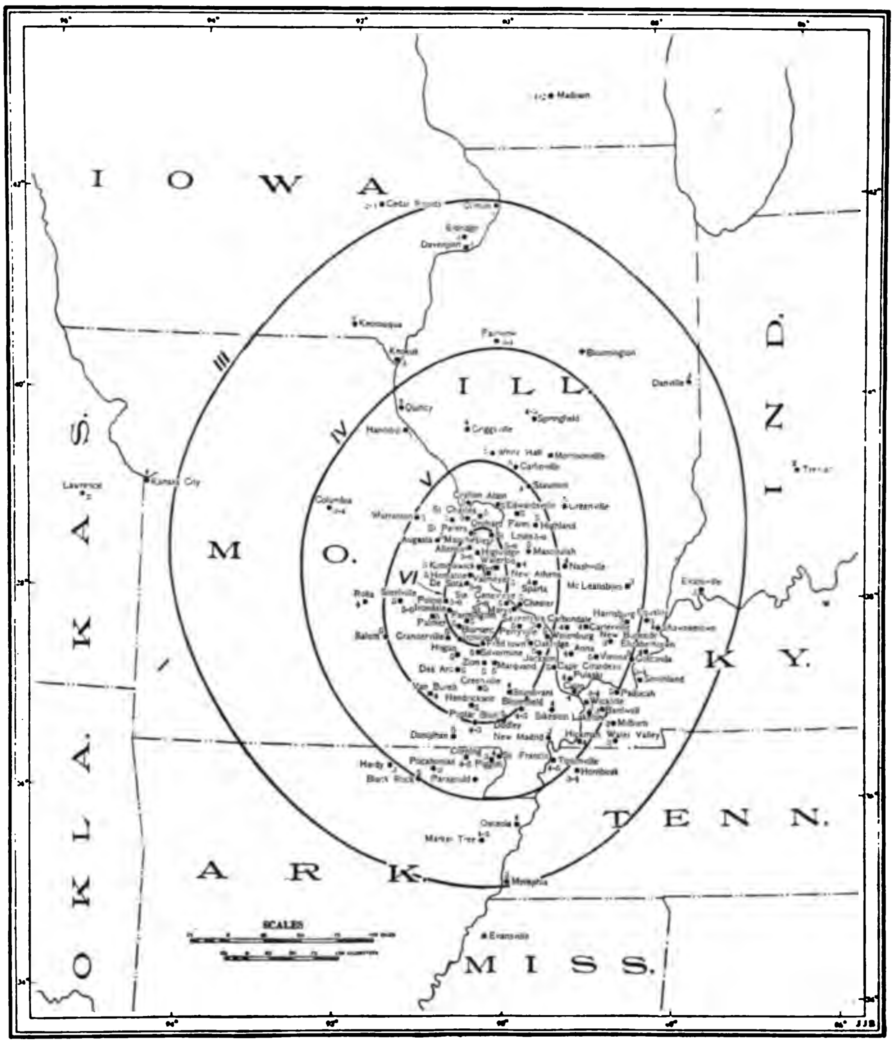


Fig. 1. Isoseismals of the Missouri earthquake of April 9, 1917. Arabic numbers opposite places indicate Rossi-Forel intensities.

sas was $2^h\ 52^m\ 24^s \pm 5^s$. This is in fair agreement with the record obtained at St. Louis University, within a very short distance of the origin, which began at $2^h\ 52^m\ 30^s$ p. m.

Sounds were quite generally reported within the territory bounded by the V isoseismal. Within the VI isoseismal many places reported that heavy rumbling both preceded and accompanied the shock.

No good evidence as to the direction of the vibrations is at hand, though the majority of the observers thought it was east-west. The observer at Ironton, Mo., Mr. W. H. Delano, says that he looked down and could see the earth rock—rise up and sway back and forth as from west to east.

The damage occasioned by this earthquake was slight. Some windows were broken, bricks were shaken from chimneys, and plaster cracked over most of the territory bounded by the VI isoseismal. Several horses were thrown to the pavement in different parts of St. Louis. A painter working on a ladder in Granite City, Mo., was shaken off and fell into a flower garden, but was unharmed. Many people hurriedly left their homes in fright. The school children at Warrenton, Mo., and several other places, were thrown in a panic and were dismissed. As is well known, birds and many other animals are more sensitive to light shocks than human beings. This may explain why a team of horses in Golconda, Ill., were uneasy and restless at the time of the shock, while the driver felt nothing.

No preliminary shocks to the main earthquake were noticed except for a slight tremor that was recorded on April 9th by the seismograph at St. Louis University, $8^h\ 45^m$ a. m. A second shock at $5^h\ 35^m$ p. m. was felt quite generally over most of the southern half of the territory bounded by the V isoseismal and was specially noticeable in the corresponding part of the VI isoseismal. This would lead one to think that the origin was located somewhere in the southern half of the VI isoseismal area.

The middle Mississippi Valley, the southern Appalachian region, the Atlantic Coastal plain in the vicinity of Charleston, S. C., northern and eastern New York and New England are the well known seismic regions of the eastern United States. Most, though by no means all, of the middle Mississippi Valley earthquakes occur in the New Madrid region. Two shocks, one occurring on May 26, 1909, the other on January 2, 1912, and described by Udden[2] apparently had their origin southwest of Chicago. Scarcely a year passes without one or more earthquakes being felt in the New Madrid region. One on October 7, 1857, whose

---

[2] *Transactions Illinois Academy of Science*, **5**, 1912.

TABLE I. REPORTS ON THE MISSOURI EARTHQUAKE OF APRIL 9, 1917.

[Observed at approximately $20^h\ 52^m$ Greenwich Civil Time.]

Station.	Approximate latitude.	Approximate longitude.	Intensity—Rossi-Forel.	No. of shocks.	Duration.	Sounds.	Remarks.	Observer.
	° ′	° ′			M. s.			
ARKANSAS								
Black Rock	36 08	91 04	3	1	10	....	Windows trembled	S. J. Howe.
Corning	36 23	90 33	4–5	1	5	Rumbling	Shook buildings	J. N. Crutchfield.
Hardy	36 19	91 22	3	2	60	None	....	A. A. Caywood.
Marked Tree	35 32	90 22	4–5	1	....	do	Furniture moved	A. R. Shearon.
Osceola	35 43	89 54	4	1	30	do	....	A. P. Smith.
Paragould	36 05	90 25	2	..	....	....	....	A. S. Snowden.
Piggott	36 22	90 10	3	1	30	....	....	J. C. Latta.
Pocahontas	36 15	90 55	2	1	60	....	....	Benedictine Sisters.
St. Francis	36 25	90 06	3-4	1	30	None	Hanging lamps swayed	J. A. Reed.
ILLINOIS								
Alton	38 54	90 12	5	2	....	None	....	Mildred Brown.
Anna	37 27	89 18	4	2	9	Rumbling	....	J. I. Bale.
Cairo	37 00	89 10	4	2	14	None	....	U. S. Weather Bure
Carbondale	37 45	89 14	4	2	25	do	Windows rattled	Prof. F. H. Colyer.
Carlinville	39 17	89 53	5	2	30	do	Radiators swayed	Dr. J. D. Conley.
Carterville	37 46	89 05	3	2	30	do	....	J. J. West.
Chester	37 55	89 50	5	1	15	Rumbling	Buildings trembled	F. C. Kennedy.
Danville	40 09	87 36	3	1	....	....	....	J. J. Lemon.
Edwardsville	38 48	89 59	5	1	....	None	....	W. H. Morgan.
Elizabethtown	37 27	88 12	4	1	....	....	Buildings trembled	
Equality	37 44	88 22	3	1	....	None	....	Elizabeth Davis.
Fairview	40 38	90 12	3–4	1	....	do	....	Abram Wilson.
Golconda	37 22	88 31	4	2	....	Rumbling	....	J. M. Ramsey.
Grafton	38 59	90 26	5	1	....	....	Buildings shook	W. T. Bymer.
Greenville	38 53	89 25	5	4	30	....	....	F. P. Seawell.
Griggsville	39 42	90 43	4	2	2	None	....	G. F. Kneeland.
Harrisburg	37 45	88 34	3	1	....	do	....	Clarence Bonnell.
Highland	38 44	89 42	5	1	....	....	....	Chas. Schuttinger.
McLeansboro	38 07	88 34	3	1	2	None	....	A. E. Wilson.
Mascoutah	38 30	89 48	5	1	60	....	....	Dr. R. F. Lischer.
Morrisonville	39 31	89 30	4	1	....	Rumbling	....	J. D. Lowes.
Nashville	38 22	89 23	4	1	....	....	....	E. D. Garlich.
New Athens	38 18	89 52	4	3	....	None	....	D. M. Fullmer.
New Burnside	37 34	88 45	3	3	30	None	....	Miss May McCabe.
Pulaski	37 15	89 11	3–4	1	....	....	....	H. Reeves.
Quincy	39 55	91 22	4	1	....	....	....	Press report.
Shawneetown	37 42	88 10	4	1	10	None	....	E. F. Armstrong.
Springfield	39 48	89 39	4-5	2	4	do	Shook buildings	U. S. Weather Burea
Sparta	38 08	89 43	3-4	1	3	....	....	W. F. Clendenin.
Staunton	39 01	89 50	4	3	....	None	....	Mary Whalen.
Valmeyer	38 18	90 19	5	1	25	Faint	....	Chas. Schaefer.
Vienna	37 25	88 54	5	1	....	....	....	C. C. Clymon.
Waterloo	38 19	90 11	5-6	3	12	Rumbling	Shook buildings	W. E. Eilbracht.
White Hall	39 27	90 25	5	1	30	Loud	....	R. B. Pearce.
INDIANA								
Evansville	37 58	87 33	3	1	....	None	....	U. S. Weather Bure
Trevlac	39 16	86 21	2	1	....	....	....	B. N. Doylan.
IOWA								
Cedar Rapids	41 56	91 39	2–3		20	....	....	J. W. Brush.
Clinton	41 50	90 13	3	3	....	None	....	E. T. Carew.
Davenport	41 30	90 38	...	1	....	do	....	U. S. Weather Bure
Eldridge	41 38	90 35	3	..	....	do	....	M. H. Calderwood.
Keokuk	40 22	91 26	3	1	2	do	....	U. S. Weather Bure
Keosauqua	40 45	91 56	3	1	2	do	....	J. H. Landes.
KANSAS								
Lawrence	38 58	90 15	2	1	....	....	....	Prof. F. E. Kester.
KENTUCKY								
Bardwell	36 53	89 01	3	2	....	....	....	Arthur Halteman.
Hickman	36 35	89 11	4	2	....	....	....	Mrs. Ella Werner.
Laketon	36 52	89 00	3	2	....	....	....	E. T. Parker.
Milburn	36 49	88 53	3	1	....	None	....	W. R. Wilkerson.
Paducah	37 06	88 37	5	1	15	Rumbling	....	E. Futrell, Jr.

TABLE I. REPORTS ON THE MISSOURI EARTHQUAKE OF APRIL 9, 1917.—*Continued.*

[Observed at approximately 20^h 52^m Greenwich Civil Time.]

Station.	Approximate latitude.	Approximate longitude.	Intensity—Rossi-Forel.	No. of shocks.	Duration.	Sounds.	Remarks.	Observer.
	° ′	° ′			*M. s.*			
Smithland	37 09	88 29	4	1	12	None	....	W. D. Threekeld.
Water Valley ..	36 35	88 50	3	..	.....	....	....	W. E. Barnes.
Wickliffe	36 57	90 05	3–4	3	30	None	....	Prof. G. M. Moore.
MISSISSIPPI								
Evansville	34 38	90 19	2	..	.....	....	....	J. M. Phillips.
MISSOURI								
Allenton	38 30	90 40	5–6	3	.....	....	Buildings swayed.......	W. M. Sevier.
Augusta	38 34	90 51	5		8	None	....	W. J. Hayes.
Bismarck	37 48	90 36	5	2	30	....	....	G. J. Goeltz.
Bloomfield	36 54	89 53	4–5	1	10	None	....	W. E. Cooper.
Cape Girardeau	37 20	89 31	5	3	.....	....do.....	....	H. L. Roberts.
Columbia	38 57	92 20	3–4	1	.....	....do.....	....	U. S. Weather Bureau.
Des Arc	37 18	90 37	5	2	30	Rumbling .	....	W. E. McKee.
De Sota	38 06	90 33	6	..	.....	....do.....	Bricks fell off chimneys.	C. C. Mitakin.
Doniphan	36 38	90 47	5	2	.....	None	....	W. W. Martin.
Dudley	36 48	90 04	5	2	50	....do.....	....	Mrs. T. J. Fields.
Farmington ...	37 47	90 24	5	2	40	Loud......	....	J. B. Smith.
Fredericktown	37 43	90 16	5–6	3	40	....	....	A. T. Lacey.
Graniteville ...	37 38	90 44	5	2	.....	....	....	Ella Sheahan.
Greenville	37 07	90 25	5	1	30	Rumbling .	....	
Hannibal	39 41	91 20	5	1	50	None	....	U. S. Weather Bureau.
Hematite	38 13	90 30	5	2	.....	Rumbling .	....	D. O. Jarvis.
Hendrickson ..	36 50	90 26	5	1	.....	....do.....	....	J. L. Harwell.
High Ridge ...	38 27	90 32	5–6	1	1 00	....do.....	....	F. H. Klemme.
Hogan	37 32	90 39	5	3	.....	....do.....	Many people alarmed ...	Bessie Wilson.
Irondale	37 51	90 38	5–6	1	1 30	....do.....	....	E. S. Tetley.
Ironton	37 36	90 37	6	2	.....	....do.....	Windows broken.......	W. H. Delano.
Jackson	37 25	89 40	5	1	1 00	....do.....	....	L. M. Bean.
Kansas City....	39 05	94 37	3	1	.....	None	....	U. S. Weather Bureau.
Kimmswick ...	38 23	90 22	5–6	2	.....	Rumbling .	....	J. J. Hilgert.
Manchester	38 36	90 31	5	1	1 00	....do.....	....	O. N. Kulhne.
Marquand	37 27	90 07	5	2	.....	....do.....	....	Blanche White.
New Madrid ...	36 35	89 32	3	..	.....	....	....	Miss Josie Smith.
Oak Ridge	37 34	89 48	5	1	.....	Rumbling .	Dishes rattled..........	E. C. Trickey.
Orchard Farm .	38 51	90 27	5	2	2 00	....do.....	....	F. H. Meyer.
Palmer	37 49	90 54	5	2	11	....do.....	Furniture moved.......	B. G. Halbert.
Perryville	37 45	89 51	5	1	15	....do.....	....	A. E. Deen.
Pevely	38 17	90 30	5–6	2	4	....do.....	....	H. J. Englebach.
Poplar Bluff ...	36 46	90 21	4–5	1	.....	None	....	Belle Kinne.
Potosi	37 57	90 46	5–6	2	30	Rumbling .	....	B. E. Flynn.
Rolla	37 57	91 45	4	1	30	....do.....	Chandeliers swayed	E. E. Harris.
St. Charles	38 48	90 30	5	1	15	None	Many alarmed.........	Louis Saeger.
St. Louis	38 38	90 12	5–6	2	6	....do.....	Some windows broken..	U. S. Weather Bureau.
St. Marys	37 53	89 59	5	2	.....	Rumbling .	....	J. J. Davis.
St. Peters	38 48	90 40	5	1	1 00	....do.....	....	A. B. Iffrig.
Ste. Genevieve .	37 58	90 02	5	1	23	....do.....	....	L. P. Kern.
Salem	37 40	91 30	5	..	.....	....	....	C. J. Carnico.
Seventy Six ...	37 45	89 38	5	1	.....	....	....	G. S. Hatch.
Sikeston	36 54	89 34	4	1	.....	None	....	W. E. Burnham.
Silvermine	37 34	90 27	5	1	.....	Rumbling .	....	Robert Meacher.
Steelville	37 58	91 20	5	1	5	....do.....	Many people frightened	J. T. Haley.
Sturdivant	37 03	90 00	4	2	.....	Faint	....	B. F. Baker.
Van Buren	36 58	91 01	4	1	.....	None	....	O. Coleman.
Warrenton	38 48	91 07	5	..	.....	....	....	Press report.
Wittenberg ...	37 45	89 32	5	1	30	Rumbling .	....	C. R. Swan.
Zion	37 26	90 17	5	..	.....	....do.....	....	E. Barker.
TENNESSEE								
Hornbeak	36 19	89 21	3–4	1	.....	....	....	D. C. Williams.
Memphis	35 09	90 03	3	2	6	....	....	U. S. Weather Bureau
Tiptonville	36 24	89 30	4–5	1	30	....	....	I. F. Lemonds.
WISCONSIN								
Madison	43 05	89 23	2	2	6	....	....	U. S. Weather Bureau.

TABLE II. AN AFTERSHOCK.
[Observed at the following places at $23^h\ 35^m$ G. M. S. T.]

Station.	Approximate latitude.	Approximate longitude.	Intensity—Rossi-Forel.	No. of shocks.	Duration.	Sounds.	Remarks.	Observer.
ILLINOIS	° ′	° ′			*M. s.*			
Anna	37 27	89 18	2	1	7	None	...	J. I. Hale.
Valmeyer	38 18	90 19		1	9	...	...	Chas. Schaefer.
MISSOURI								
Bismarck	37 48	90 36	3	1	...	...	...	G. J. Goeltz.
Cape Girardeau	37 20	89 31	3	1	...	...	...	H. L. Roberts.
De Sota	38 06	90 33	3	1	...	...	...	C. C. Mitaken.
Hematite	38 13	90 30	...	1	30	...	...	D. O. Jarvis.
Irondale	37 51	90 38	...	1	30	...	...	E. S. Tetley.
Ironton	37 26	90 37	4	2	...	Rumbling	Shook oil in lamps	W. H. Delano.
Jackson	37 25	89 40	...	1	30	...	...	L. M. Bean.
Perryville	37 45	89 51	...	1	6	...	...	A. E. Deen.
St. Marys	37 53	89 59	5	1	2 00	Rumbling	Furniture moved	J. J. Davis
Ste. Genevieve	37 58	90 02	...	..	...	...	...	L. P. Kern.
Steelville	37 58	91 20	...	..	...	...	...	J. T. Haley.
Zion	37 26	90 17	4	1	1 00	Rumbling	...	E. Barker.

origin appears to have been either a little to the south of St. Louis or near New Madrid, was not quite as severe as the one under discussion. Another that occurred on October 31, 1895, was probably the most severe since the great shocks of 1811-12. The last shock of note in this region occurred on December 7, 1915, when an intensity of V, Rossi-Forel scale, was reported. Several observers ventured the assertion that the earthquake under discussion was the most severe since the great New Madrid earthquake, and this may be true for the region about St. Louis but is improbable as regards southeastern Missouri.

Judging from the distance to which the waves of this disturbance were propagated it seems probable that the origin was at some depth below the surface. It is known that a series of faults, running in a general east-west direction, occur in the underlying Paleozoic rock of the central region of this earthquake, and it is probable that the recent shake had its origin in one or more of these faults.

SOME MEMORANDA FROM THE CHAIRMAN OF THE SCIENTIFIC COMMITTEE

By OTTO KLOTZ

In a letter to the Secretary, Dr. Otto Klotz, who was appointed chairman of the Scientific Committee by President Woodworth, has transmitted the following memoranda, which the Publication Committee wish to present to the members of the Society by publication in the BULLETIN.

I have just received yours of the 5th inst. informing me of my appointment as Chairman of the Scientific Committee of the Seismological Association of America, and I fully appreciate the honor conferred upon me.

In order to familiarize myself with the functions of the Committee and what it has done, I again perused the six volumes of our Society and found only one report—on the Rossi-Forel scale—No. 1, Vol. VI, by the Committee, and that was by our President when he was Chairman.

However, in going over these volumes I refreshed my memory, and found a number of articles that touch upon matter that falls within the purview of the Scientific Committee.

The very first article, No. 1, Vol. 1, by Professor Lawson, brings up such questions as might be relegated to the Committee. Then Palmer's article in No. 2, Vol. 5, is very suggestive; also McAdie's with its discussion in No. 4, Vol. 5; and lastly Wood's in No. 4, Vol. 6. All contain good material that still requires attention. As a working seismologist, amongst other duties, I look upon reliable records,—seismograms,—as the prerequisite to any study in seismology and geophysics, and by our geographical position am naturally more interested in tectonic than in local earthquakes, which are infrequent with us. It goes without saying that reliable seismograms furnish us the data for all our computations about an earthquake,—its location; its hypocentral energy; its intensity at the various points of observation; the speed of propagation of the various waves, involved in which are the elasticity, the density and rigidity of the material along its path; the co-efficient of absorption; in short, the seismograms give the story of the earthquake, just as the spectogram gives the story of the distant stars. But are our seismograms reliable? There's the rub. The seismograph may be insufficiently sensitive to record the first impulse to arrive; or it may be insufficiently damped and thereby exaggerate the true motion of the earth particle. Both these deficiencies are largely within the hands of the seismologist to remedy. Unfortunately the earthquakes don't behave as we want them to do. We want one momentary, instantaneous cataclysm, and be done with it. Then the records at the various stations would be of the same phase. In this respect Mexico has distinguished herself in sending us such earthquakes, notably the two of March 26, 1908. Frequently, however, the breakdown is not instantaneous and less distant stations may receive a first impulse that is absorbed before it reaches a more distant one, so that the phases read as *P* are not identical.

Now some remarks about seismology in America, and in what direction its efficiency may be increased.

STATIONS.—Altogether there are seventy-two stations of the first and second order, according to the published list in No. 4, Vol. 1, 1911, of the BULLETIN. By far the greater number thereof (45) are in the United States; Canada has five stations. North America has quite enough stations for the study of the larger questions, although their distribution is not the most favorable for research of earthquake phenomena. The distribution should be based to a great extent, although not wholly, on the idea of seismic triangulation. For this reason there should be stations at Duluth, Helena, Port Nelson, Unalaska, Dawson and Nome, supplied with instruments to record all tectonic earthquakes. Men placed in charge of instruments at new stations should be given opportunity to visit some other stations where similar instruments are installed, to learn their workings, their adjustment and idiosyncracies, and also that of seismograms. Even in established stations there is room for improvement in the thorough understanding of the instruments employed. The best results can only be obtained from properly adjusted seismographs. I think the most of us wish that a high-class instrument were mounted in Honolulu.

TIME.—Although great improvements have been made in the time record, it still requires better time. It is to be regretted that manufacturers of seismographs in order to produce a low-price instrument generally furnish a cheap clock for recording the time. This is a mistake. The daily rate may be small, while during the day there may be fluctuation of many seconds. With either telephone, telegraph or wireless available, a daily clock correction should be obtained and tabulated, entered on each sheet and applied to the seismogram readings *before* they are sent out, not a month or two *afterwards*, as was done by some European stations. For the interval of time the different phases and the determination of the distance from the stations to the epicenter, the clock correction is of course not necessary, but when we wish to deduce the absolute time of the occurrence of the shock, i. e., at the epicenter, as we now attempt to do, it is essential that the time of each station be expressed accurately in Greenwich Mean Time.

We emphasize, therefore, that each station should strive to have its time accurate to within one second, a not unreasonable request. This postulates of course that the time-scale is such that a second of time can be read on it.

INTERPRETATION.—Let us assume that the two preceding subjects, —instruments and time,—have been satisfactorily dealt with, so that we examine our seismogram with a certain degree of confidence. A tectonic earthquake has been recorded. We see the beautiful and regular sinusoidal waves and know that we are dealing with a severe shock. Unfortunately those fine markings are of no immediate concern to us, they will be later if we wish to evaluate the energy liberated by the earthquake. Our first concern is to find *P*. If there are no microseisms, which are so frequently present, there may be little difficulty in finding and seeing a sharp, offset from the straight line and showing rapid oscillations of a second or two or less. In this case we feel sure of our *P*. When micros (microseisms) are present the reading is not so simple. However, as the period of *P* is in general less than that of the micros one will generally find a tiny peak superimposed on the sinuous micros and thus locate *P*. But all this must be done with circumspection, and congruity of *P, S* and *L* if possible established. If the earthquake is a clean breakdown of a sudden adjustment of the stresses, then *PR* is frequently found soon after *P* by an increased impetus. We must remember that after the first arrival of the *P* waves others follow and a medley of waves is set up that continue till the *L* waves are well in the saddle and all traces of *P* and *S* waves have disappeared. This medley militates against accurate interpretation. Naturally the *P* wave entering upon a quiescent state of the seismograph is the only one that lends itself to absolute accuracy of a second of time. The *S* wave enters its phase whiel the effect of *P* waves is still at work, and hence the *S* is often not so sharply defined as the *P*. The greatest uncertainty, however, occurs in identifying the beginning of the *L* waves. There is no trouble in seeing *L* waves, but when we trace them back we almost invariably get into a region of uncertainty. This uncertainty is and must naturally be confined within certain limits in order to be consistent with the readings of *P* and *S* already made. Perhaps these latter may require re-reading and revision, for we must remember that there must be consistency within certain limits, based on our experience and tables. These latter, it may be stated here, although not perfect nor final, are pretty good, as shown by their application to many seismograms and the results deduced, of which we shall presently speak. It has been our experience that in general the periods of the *L* waves decrease with the lapse of time. Frequently the *L* waves start with a period of 40 seconds, which quickly dies down to 30, 24, 20, down to 12 or so, and may be resuscitated for a short interval to a longer period, say 20—24, when *L R* appears in a heavy shock. Having read *P, S* and *L* we have the data for our immediate concern. We have yet to read the maximum amplitude of our two components. Here we must confess is undoubtedly the weakest part of our interpretation. This amplitude is supposed to be some function of the energy. It is only necessary to look over the reports from various stations to see that something is wrong, for we find stations at much greater distance from the epicenter, yet report amplitudes far in excess of those much nearer, which on the face of it is untenable. Furthermore the relation that exists between the magnitude of the amplitudes for the two components *N-S, E-W,* to the direction from the epicenter is not at all apparent, as is the case with the amplitude of the first impulse of the *P* wave and upon which Galitzin based his determination of the position of the epicenter, combined with the evaluation of Δ from *S-P*. We know, or believe we know, the free period of our pendulum; we believe we know the damping ratio; we believe we know the period of the earth particle, we then consult the "magnification curves" and find the ratio between the theoretical magnification, which perhaps we have ourselves determined, and the magnification for the case in point. We apply the latter to our seismogram and enter on our sheet so many microns (μ) amplitude. How near to the real truth this is—who knows? Here is room for investigation and improvement. Let us return to the interpreted *P, S* and *L*. We turn to the Seismological Tables, which we believe are pretty generally used in America, and find first from *S-P* the appropriate Δ, and from another table the corresponding *P-O*, from which follows *O*, the Greenwich Mean Time of the actual occurrence of the earthquake. *O* should of course be the same as derived from all stations. Discordances between *O's* may be due to several causes. Firstly, clock correction; this would show itself to the full amount; secondly inaccurate reading of *P* or *S*, or both, thereby affecting Δ and *P-O;* thirdly in case of a gradual breakdown where the first *P* does not reach very distant stations, hence the records of two stations may not be of the same phenomenon, although the interpretation of each is correct; and lastly, small differences may be expected, due to imperfections of the Tables, particularly when the distances exceed 10,000 km. How closely the *O's* agree when the seismograms show well marked phases is shown by Berkeley and Ottawa records, where with several earthquakes during the present year, the difference of the *O's* was three seconds. Well may we marvel at the advance seismology has made. When stations nearly 4000 km. apart record an earthquake by different instruments; determine its distance; and give the time when it actually happened thousands of kilometers from either place within a few seconds, it is certainly gratifying. I think I am safe and correct in saying that when the observer has confidence in his interpretation of a seismogram, the discordance between such different *O's*, barring clock corrections, will fall within ten seconds. As is well known for distant earthquakes, say over 8000 km., the horizontal component of the *P* waves is weak, and is frequently not recorded, the first to be recorded being probably *PR*, but interpreted as *P* with consequent wrong distance and wrong *O*. With severe distant earthquakes it is worth while looking for *LR;* we must remember that at the anti-epicenter, the antipode of the epicenter, the intensity of the waves is increased and they start on a fresh envelopment of the surface of the earth. Even if our reading of *L* is inaccurate to a few minutes, when we find *LR*, the difference in time between the two is the time interval for the distance $40{,}000 - 2\Delta$. Taking a mean velocity for the *L* waves of 230 km. per minute, we obtain at least an approximate value of Δ, so that we can re-examine the earlier phases of *P, PR, S, SR,* and discover any glaring inconsistencies and erroneous interpretations. We may rest assured that the seismogram is always consistent within itself; it remains for us to interpret it correctly. Although there is a small margin to our present values for *P, S, L,* for any given distance, yet that has its limit, and we must avoid recording the impossible.

A subject requiring investigation is that of the *M* waves, or maximum manifestation of the *L* waves. Every observer has undoubtedly found that not every earthquake, many not, shows an easily discernible *M*, dismissing for the present the oscillations set up in the pendulum itself which of course would give an erroneous *M*. Should we be able to recognize in every seismogram for a tectonic earthquake a well-marked *M?* What relation is there in the time interval between the arrival of *L* waves and the *M?* Is the interval a function of the distance? How shall we interpret two *M's;* must there then be also two *P's* and two *S's?* What relation is there between the *M* and the depth of thrust involved?

In the velocity graph published by Wiechert & Zöppritz in 1906 Angenheister's value for *M* is included. From it we find that the velocities of the *L* and *M* waves are plotted both as straight lines with an interval of 6^m 50^s or 410^s for a distance of 10,000 km.; other distances in direct ratio thereto. It may be correct, is it correct? If a constant relation exists between the *L* waves and *M*, then we have an approximate value of the distance; the approximation depending upon the interpretation of both *eL* and *M*. *M* certainly requires further interpretation and investigation.

EVALUATION.—Due to the violent surface earthquake at Bergsturz in the Pamirs on February 18, 1911, Galitzin undertook to evaluate its energy as manifested on the Pulkova seismogram, an account of which was published by the writer together with the Ottawa evaluation for the same shock in the December number, 1915, of the BULLETIN of the Seismological Society of America, No. 4, Vol. V. Later Navarro-Neumann similarly evaluated the Cartuja seismogram. The method evolved by Galitzin, or any other method, will furnish an inter-comparison of interpretation and measurements on the seismogram, and accuracy of magnification factor employed; for the energy, *E*, found at the various stations must, as in the case of the *O*, be the same. The derivation of *E* is not quite as simple as that of *O*; this kinetic energy is one deserving of more attention by seismologists and geophysicists, for it is the most potent manifestation of energy that we experience on the earth. The evaluations would probably confine themselves to severe tectonic earthquakes whose records would give ample material for measurements. It is to be hoped that this hitherto unused part of the seismogram may find its place in the publications of stations. McAdie gives in his presidential address the energy of the great San Francisco earthquake at 316354×10^6 kilowatts (Reid), or 3.16×10^{21} ergs. For the above Pamirs earthquake the energy liberated was 4.3×10^{23} ergs.

NOMENCLATURE.—The nomenclature promulgated by the International Seismological Association seven years ago is now pretty uniformly adopted. In our Seismological Tables an important symbol, *O*, the time of the earthquake at the origin, suggested to the writer by our President, Professor J. B. Woodwort of Harvard, was incorporated and I am glad to see that in a recent report from Shide, Professor Turner adopts this symbol *O*. It goes without saying that uniformity of nomenclature is highly desirable.

BULLETINS.—Here there is room for further improvement and uniformity. This was included in the resolution together with the above nomenclature at the international conference at Manchester in 1911. The most of the American stations that issue bulletins issue them on the prescribed fools-cap sheet size. Those that do not would confer a favor on the others by falling in line with the accepted form. But of greater moment is that some, many, do not issue a bulletin, a monthly bulletin, at all, in fact some have not even an annual report. The records of such stations are practically lost to the scientific world. The lack of individual bulletins is in a measure made up by the publication in the *Monthly Weather Review* of Washington the monthly records of some twenty American stations a few of which issue monthly bulletins. From unavoidable circumstances such records are two or three months old when received. To publish only annual reports, which means probably fifteen months after a January earthquake, is not fair to the scientific world and to research. They lose very much of their value by being withheld from incorporation in seismological studies and investigations. The annual reports are desirable, but a monthly bulletin is much more so. Publish, publish, publish at the earliest possible time and make the data available to the world should be the aim of every station. Blank forms, a typewriter, a mimeograph apparatus and a few hours labor do the whole work at very small expense. The final word, let monthly bulletins be made available. A few stations have the laudable enterprise of exchanging printed form post cards immediately, giving data of a severe earthquake.

INTENSITY SCALE.—Personally I am at present more concerned in obtaining reliable seismograms and in their proper interpretation than in an arbitrary intensity scale. I quite agree with Montessus de Ballore and Branner about the unreliability of the personal estimate, and the modification suggested by the latter to the Rossi-Forel scale should answer our purpose for the present. The only scientific scale must be a dynamic one, based upon C. G. S. units.

CENTRAL BUREAU.—It was hoped that when seismology obtained a legal status at Washington a new dawn would sweep into our ken. Perhaps during these three years we have been too impatient. Let us trust that our hopes will yet be realized. The Central Bureau of the International Association did much, accomplished much, yet has not achieved that position that the writer, who has on several occasions visited it at Strassburg, expected it to attain in its usefulness to seismologists. Before we get out better tables, before serious geophysical problems involved in seismic records are undertaken, we must have better records and still more, better interpretations of the records. Some of the data are so imperfect at present that it does not seem right to incorporate them in investigations. It is believed that most seismologists,—anyway in America,—had to grope their way into the subject without any personal aid or assistance or explanation about instrument or seismogram. It is not to be wondered at that the interpreted records lack precision. We all want to improve,—there is no exception. At present the International Seismological Association Bureau is unavailable. The distribution of American stations is wide enough to furnish material to deal with world problems in seismology.

My idea of a Central Bureau (Washington) is that it be a clearing house, and intelligence bureau; a bureau to which we can send our seismograms to have them read and interpreted, subsequently to be returned each with its reading and remarks. Location of epicenters can be more efficiently done at a central bureau than at individual stations. By means of such a bureau there would in a short time result co-ordination that now is enveloped in a distant future. The study of the seismograms from various instruments would disclose defects, and defects discovered presumably lead to defects remedied. It would help to pull us out of ruts into which we unconsciously drift and keep on making erroneous interpretations. It would give new life to each station; each station would feel that it is a unit in the new structure of seismology that is trying to unravel the hidden truths of the surface and interior of our earth, which is after all the most important,—to us,—of all the heavenly bodies. To give an idea of the unsatisfactory situation with reference to earthquake records, one need only turn to the interesting compilations found in the Shide Bulletins. The latest one just received is for April and May, 1915. Glancing over it one finds differences between the observed and computed *P*, similarly for *S*, based on an epicenter computed by Shide, running to 100^s, to 300^s, to a 1000^s, and even to over 2700^s, i. e., more than 45 minutes of time. Surely there is something radically wrong. What's the use of talking about correcting our tables by a few seconds or so, when we still have material like that to deal with? Is it not our first duty to get fairly reliable records?

The bureau might properly undertake too the testing of instruments before they have been permanently set up, as has been done at Strassburg. Such testing and examinations would give greater confidence to the observer in the performance of his instrument. When we once have reliable data then the field of geophysics may be entered by those who have the necessary mathematical implements to cultivate it, taking up any particular branch of research that appeals to them. But to repeat, we must first have reliable data.

Perhaps my conception of a Central Bureau (at Washington) appears like a "pretty big order," but it is worth while if seismology is to have the scientific standing it deserves. The first year or so would undoubtedly have the heaviest drain on the bureau till all or the important stations at least would have their seismograms co-ordinated. The bureau would be expected to publish the earthquake data from the various stations, together with monographs and other matter pertinent to seismology. Such a bureau would be perfectly in line with similar bureaus already established at Washington.

OTTAWA, CANADA,
July 19, 1917.

A FURTHER NOTE ON SEISMOMETRIC BOOKKEEPING

By Harry O. Wood

Some time since the writer[1] listed and discussed the items,—quantities to be noted and measured, and corrections and computations to be made—then ordinarily considered and recorded in the routine measurement and reduction of the motion of earthquakes upon seismograms. In that paper was presented for consideration and criticism of those who work at seisometric routine a ruled blank form, analogous to the day-book or journal form of commercial bookkeeping, intended to facilitate the systematic and permanent recording of all the necessary items of the record. Suggestions looking to improvements in that blank form were asked for. But no such suggestions were ever brought to the writer's notice.

In the interval since the scheme was published, nearly five years, the writer has had to measure and reduce upwards of two thousand earthquake records. In this work he has employed the form then proposed.

A vast majority of these shocks were weak local disturbances, from origins distant mostly between 15 and 40 kilometers. In general these shock-records have been of short duration, with short periods and small, or relatively small, seismographic amplitudes. Of course the measurement and reduction of such records is simple as compared with the work necessary in the case of well registered teleseismic motion. Hence both convenience and economy suggest for employment with these local shocks a simpler blank form than that required for teleseisms.

However, even for such local shocks, a blank form somewhat different from that earlier proposed now seems desirable. None of the items originally listed and provided for upon the blanks can be omitted: but ruled colunms, for other magnitudes and factors as discussed below, appear to be needed. Also, an even more extended change in the blank forms for use in recording the measurements and reductions of teleseismic disturbances now seems desirable, to avoid the use of scratch pads with consequent loss of auxiliary jottings, measurements and computations.

---

[1] Wood, H. O., Seismographic Bookkeeping. *Bulletin Seismological Society of America*, **2**, 118-123, June, 1912.

Most of the matter in the earlier paper may be allowed to stand,—and it does not require repetition here.

However, since the earlier article was prepared certain tables have appeared and methods of work introduced, or have come into more general use, which make for improved results, and which shorten and simplify the labor of measurement and reduction. But to utilize some of these conveniently other ruled columns need to be provided upon the blank forms. Most of these helpful tables and diagrams have been brought together in the pamphlet compiled by Klotz[2]. Also new symbols have been introduced. In the revised blank forms suggested below the notation and symbols of Klotz's pamphlet are employed. In addition the well known symbol ϵ, the damping ratio, r, the frictional displacement of the medial line, and a, the acceleration of the vibratory motion of the earth particle, are used. This procedure should go far toward making the forms self-explanatory.

Klotz's tables do not incorporate those prepared by Zoeppritz[3] to aid in computing the magnitude of seismic earth motion; nor is Geiger's[4] improved method, based upon Zoeppritz's tables, included. But, those who utilize Geiger's method and diagram, or Zoeppritz's tables directly, will find convenient a column provided for the magnitude $\sqrt{S}$, a symbol not found in Klotz's pamphlet,

$$\text{where } \sqrt{S} = \sqrt{\left\{ 1 - \left(\frac{T_e}{T_o}\right)^2 \right\}^2 + 4\left(\frac{T_o}{2\pi\tau}\right)^2 \cdot \left(\frac{T_e}{T_o}\right)^2}$$

$$\text{in which } \left(\frac{T_o}{2\pi\tau}\right)^2 = \frac{(\log.\ nat.\ \epsilon)^2}{\pi^2 + (\log.\ nat.\ \epsilon)^2}, \text{ or practically } \frac{0.538\ (\log._{10}\epsilon)^2}{1 + 0.538\,(\log._{10}\epsilon)^2}$$

For description of methods of Zoeppritz and Geiger readers must be referred to the original papers.

For those who prefer to utilize magnification curves, such as those published by Weichert, Reid, and Klotz, the following mere outline of a slide rule method of reduction of A_μ and $a\gamma_\mu$ may be useful. To working seismologists it should be self-explanatory. Its use makes convenient columns for the ratios T_e/T_o and $\mathscr{M}a/\mathscr{M}$.

---

[2] Klotz, Otto, Seismological Tables. *Publications Dominion Observatory, Ottawa,* **3**, 2, 1916.

[3] Zoeppritz, Karl. Hilfstabellen zur Berechnung der Bodenbewegung. *Nachr. Kgl. Gesellsch. Wissensch.* Göttingen. Math.-Phys. Klasse, **2**, 138-148, 1908.

[4] Geiger, Ludwig. Hilfsmittel zur Berechnung der wahren Bodenschwankung. *Nachr. Kgl. Gesellsch. Wissensch.* Göttingen. Math.-Phys. Klasse, **2**, 156-165, 1909.

[The M's in the following formulae should be the same as in the preceding line.—*Editor.*]

With ϵ, T_e and T_0 found by measurement, and T_e/T_0 computed or derived from tables,—find from a curve-family diagram, such as that published by Klotz.

$Ma/M = f\ (T_e/T_0, \epsilon) =$; then computing, $1000/2M = C =$.

To reduce A_μ from $2A$ measured in mm.

FORMULAS

Waves of very short period	Waves of longer period
$A_\mu = 2A_{mm} \cdot C$	$A_\mu = \dfrac{2A_{mm} \cdot C}{Ma/M}$

SLIDE-RULE SETTINGS

Simply multiply

A	Under $2A_{mm}$	Find A_μ	A
B	Set Ma/M	Over C	B

To reduce $a\gamma_\mu$ from measures of $2A_{mm}$ and T_e.

FORMULAS

Waves of very short period	Waves of longer period

$$a\gamma_\mu = \frac{2A_{mm} \cdot 4C}{T_e^2} = \frac{4A_\mu}{T_e^2} = \frac{2A_{mm} \cdot 4C}{Ma/M \cdot T_e^2} = a\gamma_\mu$$

SLIDE-RULE SETTINGS

A	Under $2A_{mm}$	Find $a\gamma_\mu$
B		Over $4C$
C	Set T_e sec.	
D		

A_μ	$a\gamma_\mu$
	4
T_e sec.	

Under $2A_{mm}$			Find $a\gamma_\mu$	A
	Move R to $4C$	Set Ma/M to R	Over 1	B
Set T_e sec.				C
				D

Also the symbol I, for intensity [best stated in terms of the Cancani scale], not given in Klotz's tables, is employed upon the blank forms here proposed. [In strict terms the energy $I = 2\pi^2 I' D \frac{a^2}{T_e^2}$].

The minute intervals upon seismograms cannot usually be divided exactly into sixty equal parts by the application of a scale, since the power clocks which drive the recording surfaces have variable rates under varying conditions of temperature, etc. So, in determining times in terms of seconds the writer is accustomed to measure the minute interval at the time involved in small units such as quarter-millimeters, or hundredth-inches and then the seconds-interval in the same unit (whether a duration, as in the case of a period, or a time-lapse after the minute mark, as in the case of a phase-beginning), thus forming a seconds-fraction ($16/57 \times 60$, for example) the reduction of which with the slide-rule is a simple and rapid operation. It has, however, been found desirable to preserve the record of the measured second-fractions. So, when they are needed, columns are provided for these in the revised blank forms.

To save space in the vertical dimension a column is provided for the corrected phase times expressed in terms of Greenwich Mean Civil Time; and this change from the older form makes necessary a column, $A\mu$, for amplitudes reduced to microns, since the procedure previously followed is no longer feasible.

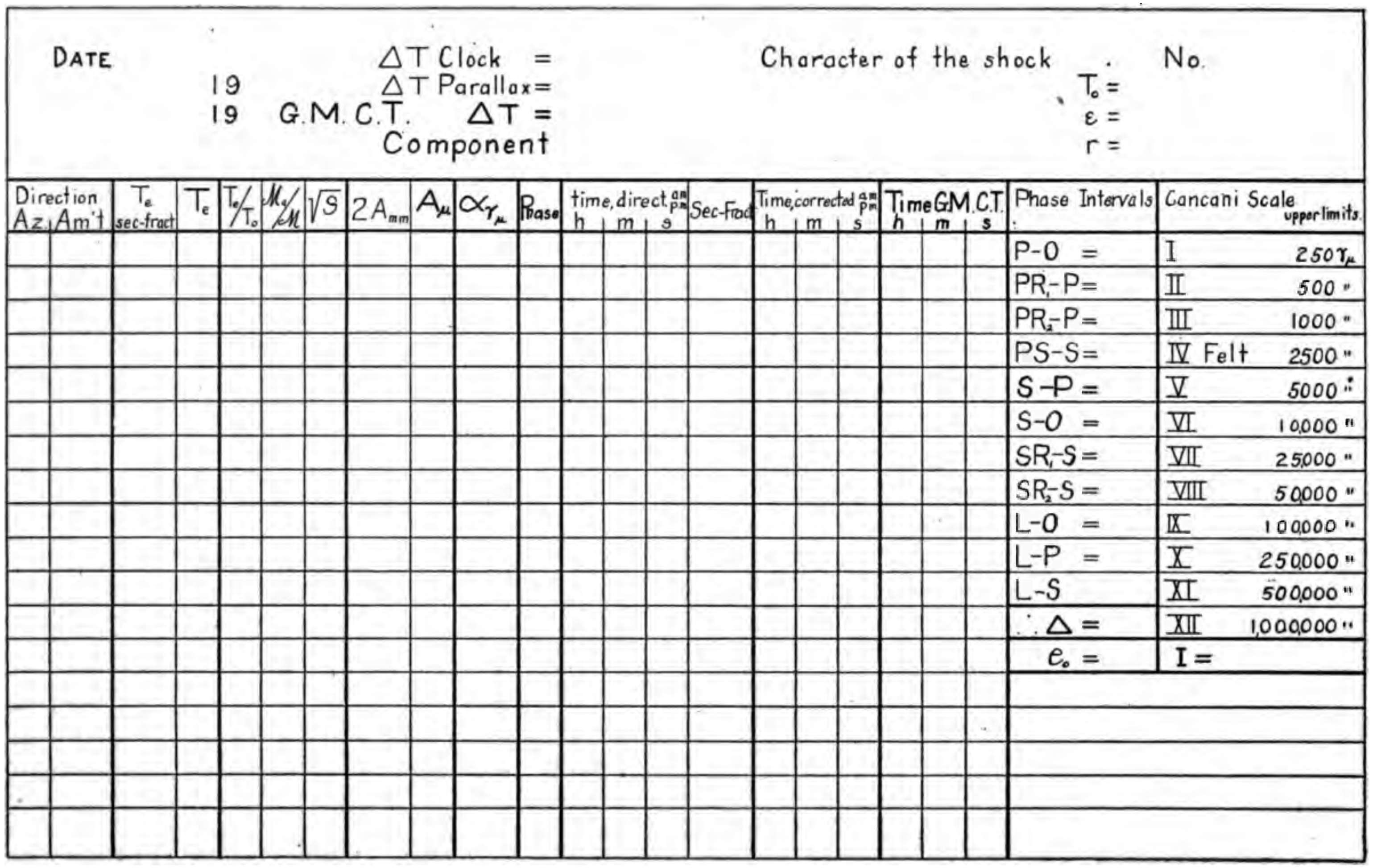
Place is indicated for recording the phase-intervals commonly measured, and for Δ, e_0, and I. Also the grades of the Cancani scale and their upper-limit acceleration of magintudes are given, for convenience. Thus a small space is left for remarks, which, of course may also be written in any unused portion of the blank, or on its back.

For the reason stated above two blank forms are illustrated below. Nevertheless, the more complete of these, Fig. 1, may be employed for record of small local shocks as well as for the more complicated records of teleseismic disturbances. At most stations, where there is no great preponderance of local shocks, the more complete form should suffice for all sorts of records. But where weak, local shocks are registered in far greater number than teleseisms, convenience and economy of time suggest the employment of a less complete form also, for these local shocks. It even seems desirable that such shocks should be listed separately in the form of final publication, for which the procedure suggested would have an added advantage. See Fig. 2.

With regard to the format of such record blanks:

The work of measurement and reduction for a great majority of the shocks of both categories,—as generally published up to the present—could be recorded conveniently for a single component in the space afforded by a 5x8 inch catalog card. In the case of the few shocks for which more space might be needed continuation cards could be employed. For those who prefer a loose-leaf system, or a book, the same ruling could be upon printed sheets, or pages, of the 5x8 inch ize, or larger. With a loose-leaf system, as with the cards, continuation sheets could be used where needed.

Either cards, or loose sheets, may be perforated to suit the user, or left unperforated.



DATE
19
19 G.M.C.T.

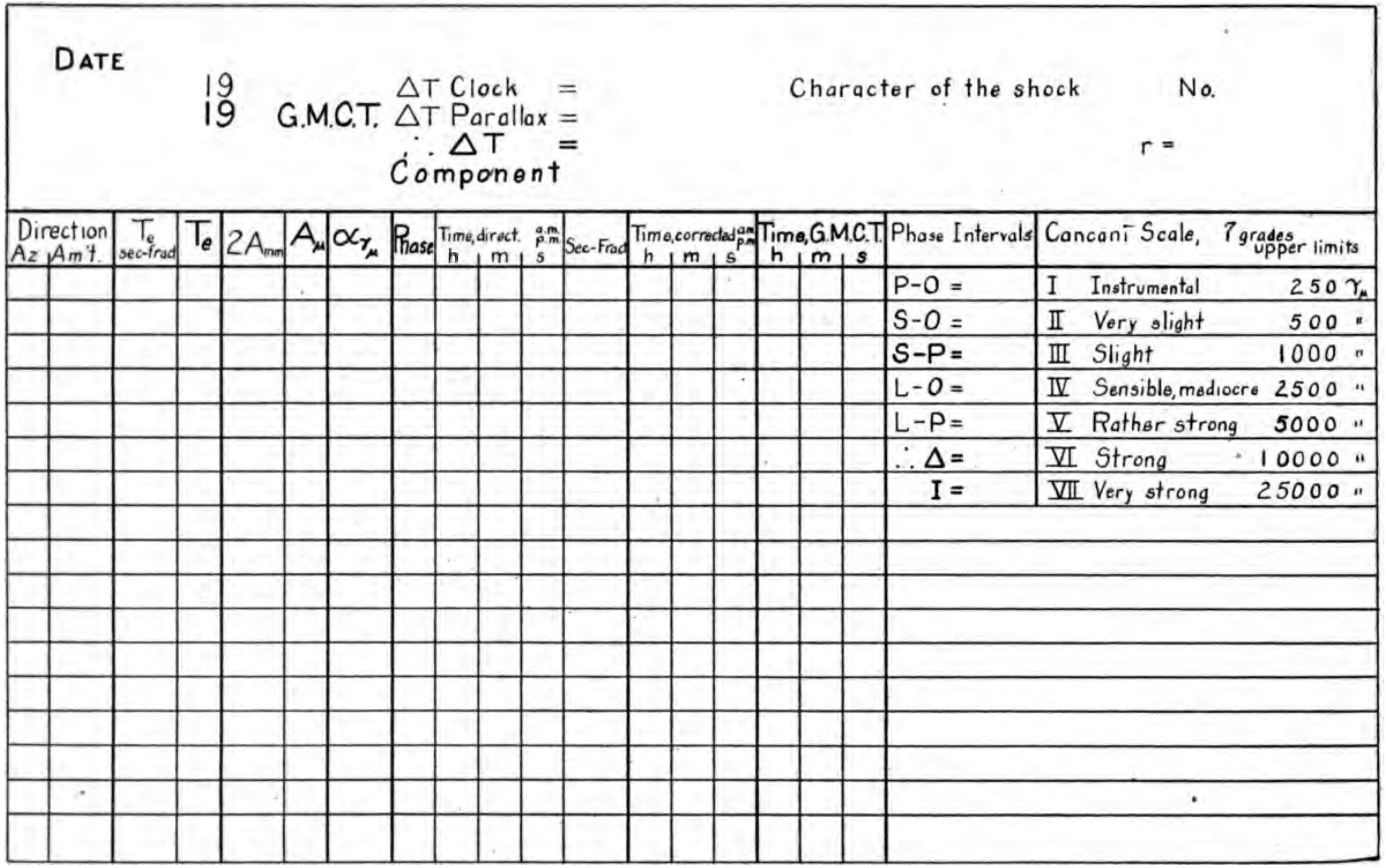
ΔT Clock =
ΔT Parallax =
ΔT =
Component

Character of the shock
T_0 =
ε =
r =

No.

Direction		T_e sec-fract	T_e	T_e/T_0	M_e/M	$\sqrt{S}$	$2A_{mm}$	A_μ	α_{γ_μ}	Phase	time, direct am pm			Sec-Fract	Time, corrected am pm			Time G.M.C.T.			Phase Intervals	Cancani Scale upper limits
Az	Am't										h	m	s		h	m	s	h	m	s		
																					P-0 =	I $250\gamma_\mu$
																					PR_1-P =	II 500 "
																					PR_2-P =	III 1000 "
																					PS-S =	IV Felt 2500 "
																					S-P =	V 5000 "
																					S-O =	VI 10,000 "
																					SR_1-S =	VII 25,000 "
																					SR_2-S =	VIII 50,000 "
																					L-0 =	IX 100,000 "
																					L-P =	X 250,000 "
																					L-S	XI 500,000 "
																					∴ Δ =	XII 1,000,000 "
																					e_0 =	I =

Fig. 1. Complete Form



DATE

19

19 G.M.C.T. ΔT Clock =

ΔT Parallax =

$\therefore \Delta T$ =

Component

Character of the shock No.

r =

Direction		T_e sec-frad	T_e	$2A_{mm}$	A_μ	α_{γ_μ}	Phase	Time, direct.		a.m. p.m.	Sec-Frac	Time, corrected		a.m. p.m.	Time, G.M.C.T.			Phase Intervals	Cancani Scale, 7 grades upper limits		
Az	Am't.							h	m	s		h	m	s	h	m	s				
																		P-O =	I	Instrumental	250 γ_μ
																		S-O =	II	Very slight	500 "
																		S-P =	III	Slight	1000 "
																		L-O =	IV	Sensible, mediocre	2500 "
																		L-P =	V	Rather strong	5000 "
																		$\therefore \Delta$ =	VI	Strong	10000 "
																		I =	VII	Very strong	25000 "

Fig. 2. Abridged Form

Also, at more completely equipped stations, where different types of seismometers are in use, cards or loose sheets of different colors may be employed to differentiate types, or components.

With certain types of seismometers special computing blank forms are necessary, or very desirable; but as these are not of general application discussion of them does not properly find place in this note.

The blank form analogous to the ledger of commerce described in the earlier paper,—being simply the standard form adopted for the publication of seisometric results,—needs no change at present.

Thus far the writer has not printed the modified record blanks here described and discussed. But in trials made with forms ruled by hand he has found them satisfactory. However, he asks urgently for critisisms and suggestions looking to their improvement,—or for alternative schemes more suitable to the uses for which these have been designed.

HAWAIIAN VOLCANO OBSERVATORY,
March 17, 1917.

MISCELLANEOUS EARTHQUAKES IN SOUTHERN AND EASTERN CALIFORNIA

By HOMER HAMLIN

San Miguel, California, June 8, 1917.—An earthquake was felt at San Miguel, San Luis Obispo County, on June 8, 1917, at 7:34 p. m. There was but one shock which began abruptly, consisted of a trembling motion, and lasted for about one second.

It was felt by several persons standing, and caused distinct jarring of buildings and slight swinging of suspended electric light bulbs. The intensity is estimated to have been about IV. This information was furnished by Mr. E. G. Hamilton. I have no other reports concerning this earthquake, but it was probably felt over a considerable area in the upper Salinas Valley.

Owens Valley, California, June 21, 1917.—An earthquake was felt in Owens Valley on June 21, 1917, at 11:20 a. m., at the Division Creek Power House about 11 miles northwest of Independence, California, near the foot of the Sierra Nevada range. There was a single shock which consisted of a rocking motion which caused a jarring of the building. The shock was observed by three persons, and is estimated to have had an intensity between IV and V, R.-F. scale. It was not observed at Bishop.

Los Angeles, California, June 24, 1917.—An earthquake occurred in Los Angeles, California, on June 24, 1917, at 12:00 noon. It was felt by persons at rest, caused a distinct jarring of buildings and rattling of windows, dishes and other small articles. It was described as one abrupt bump. It is estimated that the intensity was between III and IV.

Another shock of about the same intensity was felt at 12:30 p. m. and in another locality still another lighter shock. This earthquake was felt only in the southern part of the city, as far as could be learned. This information was furnished by Mr. E. S. Ross and Miss C. N. Peterson.

Los Angeles, California, June 25, 1917.—An earthquake was felt in Los Angeles, California, on June 25, 1917. The first shock occurred at 8:15 p. m. and a second one at 8:24 p. m. The first shock was felt by several persons at rest. It caused distinct jarring of buildings, slight rattling of doors, windows, dishes, etc. There was but one shock which was described as a jolt. The estimated intensity was about III-IV.

The second shock was probably of greater intensity than the first, having been reported from another point. So far as known both shocks were noticed only in the southern portion of the city within the same region where the shock of June 24th was noticed. The information was furnished by Mr. J. P. Naff, Mr. O. McAleer, and Mr. M. B. Peterson.

Los Angeles, California, June 26, 1917.—An earthquake was felt in Los Angeles, California, on June 26, 1917, at 3:51 a. m. It began abruptly with a trembling motion. There was one shock of about three seconds duration, which distinctly jarred buildings. Estimated intensity about III. The shock was reported by but one observer, Mr. J .A. Slenitzaur. The shock was also felt in the southern portion of the city.

Los Angeles, California, June 26, 1917.—An earthquake occurred in the southern part of Los Angeles, California, on June 26, 1917. The first shock was felt at 1.15 p. m., the second at about 1:20 p. m., and the third at about 1:25 to 1:30 p. m.

Most observers state that the earthquake began as an abrupt bump; others state that it began as an abrupt rocking motion, and others describe it as a trembling motion. Evidently the observers' situation relative to the epicenter explains this difference.

The shocks were hard enough to be felt by persons standing. Estimated intensity V to VI. Many persons in the southern part of the city left their homes and ran into the streets or yards. Buildings were shaken; doors, windows, dishes, etc., rattled. In what was supposed to be the epicentral area the first shock, especially, was preceded by a roaring or rumbling sound.

Los Angeles, California, June 28, 1917.—An earthquake was felt in Los Angeles, California, on June 28, 1917, at 9:50 p. m. There was one abrupt bumping shock with a duration of from one-half to one second. It was hard enough to be felt by persons standing. The estimated intensity was about IV. In the southern part of the city buildings were distinctly jarred, windows and doors were shaken and a rumbling sound was heard during the shock in some places. Six reports were reecived of this earthquake.

Los Angeles, California, June 28, 1917.—An earthquake was felt in Los Angeles, California, on June 28, 1917, at about 10:25 p. m. The intensity was probably about IV in the southern and about II in the central part of the city. It was reported by two observers several miles apart.

Los Angeles, California, June 29, 1917.—An earthquake was felt in Los Angeles, California, on June 29, 1917, at about 4:00 p. m. There was but one shock, which began abruptly and consisted of a trembling motion. It was noticed by about a dozen persons at rest. Buildings were swayed decidedly, and there was a distinct rattling of doors, windows, etc. The intensity was estimated at III to IV of the R.-F. scale.

Los Angeles, California, June 30, 1917.—An earthquake was felt in Los Angeles, California, on June 30, 1917, at about 3:45 p. m. It was of about the same intensity as the shock which occurred on the afternoon of June 26th (between III and IV), and the disturbed area appears to have been about the same. About forty reports have been received on this earthquake, but the data have not been studied yet. The records of this shock are far from complete.

Owens Valley, California, July 6, 1917.—A shock was felt in Owens Valley, July 6, 1917, at 3:01 a. m. It was observed at the Division Creek Power House, where the single shock was abrupt with rapid rocking, trembling, and twisting motions as described by Mr. L. L. McAfee. The shock was hard enough to jar the buildings decidedly, caused wrenches and tools hanging on the walls to swing and stopped a pendulum clock at 3:00 a. m. The needles of the recording electrical instruments at the power house were seen to oscillate during the earthquake. A slight rumbling sound was heard at this point just before the shock was felt.

This earthquake was also reported from Lone Pine, 16 miles southeast of Independence. Here it was described by one observer as a trembling motion which caused a slight jarring of buildings and slight shaking of furniture.

It was also felt at Little Lake on the Los Angeles Aqueduct, about two miles northwest of the railroad station of the same name. Here a very slight shock was reported as having been felt at 3:20 a. m. It was probably the same earthquake.

I have been unable to get any information about this earthquake at points north of Division Creek, except that it was apparently not noticed at Bishop. It was probably felt some distance north of Division Creek, however. From the data at hand it appears that a narrow belt of country about one hundred miles long was shaken on July 6th, and a much smaller area on June 21st. These earthquakes seem to have originated in the great fault zone along the eastern front of the Sierra Nevada Mountains.

Arroyo Grande, California.—A series of earthquakes in the vicinity of Arroyo Grande, San Luis Obispo County, has been reported by Mr.

Stephen J. Rhyne, Forest Ranger. They occurred on July 7, 8, and 9, 1917. Mr. Rhyne is stationed in Lopez Canyon about ten miles in an air line from Arroyo Grande and the same distance from San Luis Obispo.

The first earthquake, on July 7, began with a shock at 12:59½ p. m. It was followed by another shock at 1:01½ p. m. and by a third shock at 1:14¾ p. m. Each shock was of about five seconds duration and consisted of a trembling motion which came on rapidly. Mr. Rhyne reports that the shocks were felt generally by everyone; they caused decided jarring of buildings, shaking and rattling of doors, windows and a creaking of floors and ceilings and violent swinging of hanging objects. A roaring sound was heard after each shock. The intensity is estimated at V to VI, R.-F. scale.

The second earthquake, on July 8, was a single shock, so far as observed, and occurred at 3:29 a. m. It began gradually and consisted of a trembling motion. It was felt by several persons at rest, caused distinct swaying of buildings, rattling of dishes, doors, windows, etc., and was accompanied by underground sounds. The estimated intensity was IV.

The third earthquake, of July 9th, consisted of four distinct shocks, the first at 2:22 p. m., the second at 2:38 p. m., the third at 4:43 p. m., and the fourth at 4:45 p. m. The duration of each shock was estimated at possibly five seconds. The shocks, which came on gradually and consisted of a trembling motion, were felt generally by everyone. They caused violent swaying of buildings, distinct rattling of dishes, doors, windows, etc., a distinct creaking of buildings and decided swaying of hanging objects. A rumbling sound was heard after the shocks. Dishes were overturned, rocks rolled down the hillsides and chimneys were damaged. The intensity is estimated to be from VI to VII.

Mr. Rhyne says that the shocks on July 9th had a decided swinging motion and were felt by nearly everyone in that locality.

Sierra Madre, California, July 15, 1917.—An earthquake occurred at Sierra Madre, California, and vicinity on July 15th at 11:05 a. m. At Sierra Madre one shock only was felt, beginning suddenly and consisting of a trembling motion, one or two seconds in duration. It was felt generally by every one indoors and caused distinct jarring of buildings, rattling of doors, windows, dishes, etc. At Monrovia the time was reported as 11:02, where one shock only was noted, of about two seconds duration. Here it was generally felt, began abruptly, and is reported to have consisted of a quick sideways twist. Buildings jarred and creaked, doors, windows, etc., rattled slightly, and the shock was accompanied by a loud underground sound.

At the Mt. Wilson Solar Observatory two shocks were noted, beginning at 11:05 a. m. The time was reported by Mr. W. P. Hoge as correct within one minute. The shocks came abruptly. The vibrations are said to have been vertical. The shocks were short, of about one to two seconds duration, with an interval of about two seconds between the shocks. The earthquake was felt by several persons. Frame houses creaked slightly and faint underground sounds accompanied the shocks.

Another observer on Mt. Wilson gives the time as about 10:45 a. m., states that there were two shocks with a bumping motion, and that doors, windows, etc., rattled slightly.

The estimated intensity at Sierra Madre was IV, at Monrovia IV, and at Mt. Wilson III. This earthquake was probably caused by a slip on the fault plane along the south side of the San Gabriel Range. The Mt. Wilson Solar Observatory is on a granite mountain, north of the fault. Sierra Madre and Monrovia are both on alluvial soils, formed of debris from the range to the north, and both places are near the fault zone. Personally I do not know the exact location of this fault, but it is in that vicinity.

Los Angeles, California, July 17, 1917.—On July 17, 1917, a slight earthquake was felt in the southern part of Los Angeles, California. Two observers report that there were two shocks, one at 3:15 p. m. and the other at 3:19 p. m. Another observer reports one shock at 3:30 p. m. It is reported that the shocks were felt by several persons at rest, that the shocks began with a rocking motion, that buildings swayed distinctly and that suspended electric light bulbs swayed slightly.

At another locality buildings creaked and a rumbling noise like distant thunder was heard. One person asleep in the second story of a frame building was awakened by the shock. The intensity is estimated at IV of the R.-F. scale.

Los Olivos, California, July 26, 1917.—A slight earthquake was felt at Los Olivos, California, on July 26 at 12:50 a. m. There was but one shock which began gradually and consisted of a trembling motion of twenty to twenty-five seconds duration. It was felt generally by persons at rest, and was accompanied by a roaring sound. The estimated intensity was III to IV. It was reported by Mr. Joseph J. Lieben, Forest Ranger.

Los Angeles, California, August 3, 1917.—A slight earthquake was felt in Los Angeles, California, by two persons, both at the same locality. It occurred on August 3, 1917, at about 2:10 a. m. It began rapidly and consisted of a rocking motion. It caused a distinct jarring of buildings, a slight creaking of the house and slight rattling of doors and windows. It was preceded by a rumbling sound like thunder. The estimated intensity was about III. Reported by Miss Helene Lee.

Coachella, California, August 12, 1917.—An earthquake occurred at Coachella, California, on August 12, 1917, at about 3:00 a. m. There appears to have been but one shock with a rocking motion, beginning gradually. It was estimated by Mr. J. H. Ramsdale, who reported this shock, that 20 per cent. of the persons in that locality were awakened by the earthquake. Buildings swayed distinctly, dishes and small articles rattled, and the shock was preceded by a roaring sound. The estimated intensity was from IV to V.

NOTES CONCERNING THE RAGANG VOLCANO AND A GREAT EARTHQUAKE IN SOUTH MINDANAO

By Miguel Saderra Masó

The following notes, by Rev. Father Masó, were transmitted to the Bulletin through Professor Warren D. Smith of the University of Oregon.—*Editor.*

Ragang Volcano, Mindanao.—In the month of July, 1916, during a Constabulary patrol through the region situated between Lake Lanao and Cotabato, Lieut. W. F. Donnelly, P. C., came in sight of an active volcano which from all indications had recently erupted a discharge of volcanic ash and vapors capable of partially destroying the vegetation for 3.5 kilometers around.

Later, in September, Col. P. E. Traub, U. S. Cav., Chief of the District, greatly interested in the discovery of Lieut. Donnelly, undertook a second expedition in company with Capt. G. O. Fort, P. C., and the said lieutenant to locate the crater and examine its actual state of activity. Arriving in the region, the party met with some difficulty in discovering the volcano, on account of the fog. When the fog lifted they saw a group of three peaks or cones with a deep hollow in the center between them. From the hollow or crater, apparently extinct at present, there radiates toward the southeast an old current of broken and jagged lava extending about three kilometers. In some places the lava, not so broken, presents the slaggy and corded type characteristic of some recent Vesuvian flows. All around the cones and crater the products of former eruptions are scattered in the order of their size, boulders and bombs, pedregal, sand and ashes, to a great distance. The actual activity is shown by numerous jets of surphurous vapor issuing from vents distributed in the interior faces of the cones, forming the broken crater, and in the current of lava. At present the most active center is a great fissure, about thirty meters long and five wide and deep, opened across one of the cones. This crater seems to have been the origin of the last and very recent outburst; it is steaming energetically but filling up with loose material carried down its walls by the rains. There are all around the principal cones, other extinct vents, some in the shape of small cones and some of cracks and crevasses.

Capt. Fort, in his interesting report, for the perusal of which, to extract all the given details, we are greatly indebted to the courtesy of Gen. H. Hall, advances the opinion that formerly there existed four peaks around the crater, but the one in the southeast was blown up by violent explosions, the open breach giving an outlet to the molten lava.

The position of the new volcano is approximately 124° 29′ E., and 7° 40′ N.; it occupies the north end of a line of extinct but relatively modern volcanic cones, which, in a E.NE.-W.SW. direction, extends to the old Makaturing. This volcano, according to the last map of the Bureau of Constabulary, is situated at about 124° 19′ E. and 7° 36′ N.

This volcanic line seems recent compared with other cones of the country and specially with the powerful currents and layers of basalt found in the Lanao section. All this zone occupies the heart of the part of Mindanao occupied and exclusively controlled until quite recently by the Moros. For this reason it remained for centuries unexplored by outsiders. That the Ragang volcano has been constantly more or less active is evident from the meaning of the name "Palao Ragang," "the mountain where smoke or fire rises," by which it is known among the Moros. There exist, moreover, some historic but vague reports which indicate the occurrence of recent volcanic eruptions in this section. Such reports refer to occasional falls of ashes in different towns of the coasts north and south of Mindanao. The last fall was reported from the District of Dapitan, where in April, 1873, appeared a big black cloud with a consequent rain of ashes, coming from the interior,—southeast or south.

The present state of the slaggy flow from the Ragang volcano and of the ashes, lapilly and volcanic blocks, scattered all along the coast of the Illana Bay, seems to suggest the occurrence of tremendous and relatively recent eruptions, may be shortly before, and perhaps even after the discovery of the Islands. Undoubtedly the whole narrow neck or isthmus lying between the Iligan and Illana bays and which unites the Zamboanga Peninsula to the main body of Mindanao Island, has been in preceding epochs the field of great volcanic activity, owing to volcanic action its present relief and perhaps its upbuilding.

GREAT EARTHQUAKE IN SOUTH MINDANAO.—A great earthquake occurred on the 31st of Januory at $8^h\ 02^m\ 42^s$ (G. T.) $11^h\ 37^m\ 42^s$ (L. T.) and shook the whole island of Mindanao and the eastern part of the Jolo Archipelago. The epicenter was probably at some distance south of the Saragani Bay, in the Celebes Sea, where from time to time originate similar extensive earthquakes. The last one reached destructive intensity VIII-IX in the region of Glan, southeast and east of Saragani Bay.

In the following extracts, due to the courtesy of Chief of the Philippine Constabulary Col. H. Hall, are described some particulars of the earthquake and of the damage done by the same. This earthquake was really a great tectonic disturbance registered in all the observatories.

Extract from narrative report of the Senior Inspector of Cotobato for the month of January, 1917:

"A severe earthquake occurred in Glan and vicinity at 11:35 a. m., January 31, 1917, which lasted about one minute. Eighteen (18) houses were wrecked in Glan and Glan Padidu and seven (7) people killed in the barrio of Tuyan by a great landslide caused by the earthquake. All the Constabulary buildings at Glan were wrecked, except the new addition to the barracks, and one soldier, Private Paris, and one prisoner, Mamayu Gas, were slightly injured by falling timbers. The government dock at Glan was so badly damaged that it can scarcely be used for anything until extensive repairs have been made. The new storeroom of the Colony Store that was just recently built was completely destroyed and the other colony buildings so badly damaged that they will not be worth repairing. The school house in Glan was wrecked and has been abandoned, school being held in the public dispensary until another place can be arranged. The surface of the ground cracked open in some places a width of from two to three feet and in several places water and mud were thrown several meters into the air. A tidal wave of about four feet came in a few minutes after the earthquake. The damage to all government buildings, property and supplies is estimated at $4,510.69. There have been many light earthquakes at irregular intervals during the day and night ever since the severe shock of the 31st of January."

Narrative report of Cotabato for the month of February, 1917:

There were eight heavy earthquake shocks recorded in the Glan section during the month, and many light shocks. On February 14th there was quite a severe shock which shook down several houses that had been practically wrecked by the earthquake of January 31st."

SEISMOLOGICAL NOTES

Iowa City, Iowa, April 9, 1917.—(By Dr. George F. Kay, State Geologist.)—A slight earthquake was felt distinctly by many persons at Iowa City, Iowa, on the afternoon of April 9, 1917. All of the persons who reported that they felt the shock were seated, lying down, or standing inside of buildings when the shock was detected. Those who were on the higher floors of buildings reported more distinctive evidences of the shock than did those who were nearer to the ground. The only statement that can be made regarding the time of the shock is that it occurred at about 2:54 o'clock in the afternoon. Several persons reported two slight shocks; one person reported three shocks.

The shock was not only felt, but windows, doors, and furniture rattled, movable objects swayed, and houses and other objects trembled. Similar effects were reported from many places in southeastern Iowa, including Keokuk, Burlington, Ottumwa, Lineville, Muscatine, Davenport, Clinton, Bellevue, Mount Vernon, and Cedar Rapids. At Cedar Falls one person is reported to have felt the shock. Reports from Sioux City, Ames, Mason City, Dubuque, Des Moines, Council Bluffs, and Indianola state that no persons in those localities detected the earthquake.

On the afternoon of the same day shocks were felt in Missouri and Illinois. (The epicenter of this earthquake was near St. Louis, Missouri. See the paper by Mr. Finch in this number of the BULLETIN.—*Editors.*)

Point Loma, California, May 27, 1917.—Mr. Frederick J. Dick reports a light shock at Point Loma Observatory at 10:07 p. m. with an intensity of III of the R.-F. scale. It lasted between two and three seconds, and had an amplitude of 400 microns in both n. s. and e. w. directions.

Eruptions and Earthquakes, Unga, Alaska, May 30, 1917.—The newspapers report that the Pavlof and Shishaldin volcanoes in the Alaskan peninsula were in violent action in May and early June. An earthquake shock was felt at Unga at 10 p. m. on May 30th. It is said to have lasted two minutes.

Yacuiba, Bolivia, May 31, 1917.—(By Robert Anderson.)—An earthquake is reported to have ocurred at Yacuiba on May 31st. Sr. Roque Borsano, Argentine vice-Consul here, informs me that it occurred at 5:20 a. m. May 31, that there were three shocks of about two seconds each separated by intervals of one minute each, that nothing fell from shelves or houses (which are low and of adobe, with wooden frames), but that the shocks were so strong as to make everything rattle and to cause everyone to run out into the streets. The following day, June 1, at 3:30 a. m., there was a slight shock. These earthquakes were the first felt here since 1913, when there was a slight shock, and previous to that there was an earthquake in 1899 which destroyed the town.

Yacuiba is situated within a mile east of the foot of the easternmost range of the Andean mountain province, in a small valley less than two miles wide that separates the supposed Mesozoic rocks of the mountains from a low belt of foothills, of later and presumably Tertiary strata, which within a few miles farther east give place to the vast plains of the Chaco. The valley of Yacuiba is fairly flat, with an alluvial cover that is probably shallow, and structurally I think it is a faulted syncline, although I have done no work in the immediate vicinity. The fault, if it exists, is comparaticely local and can hardly be considered a major fault.

The shocks of May 31st and June 1st were not felt at Embarcacion, about 110 miles to the south of here, nor at Villa Montes on the Pilcomayo River some 60 miles to the north of Yacuiba, these three places being along what is virtually the same geologic and geographic belt.

Yacuiba is about a kilometer south of the 22nd parallel of south latitude, which is the boundary between Argentine and Bolivia, and its possession is in dispute between the two republics. But it an old Bolivian town and is still administered by Bolivia.

Samoa, June 25, 1917.—The severest earthquake felt in the Samoan Islands for many years was experienced on June 25th. The tremor is said to have lasted five minutes, and was accompanied by a tidal wave. No serious damage was done, however.

Rome, Italy, July 9, 1917.—A sharp earthquake shock was felt at Rome, Italy, on the morning of July 9, 1917. No damage was done.

Argentine Republic, July 27, 1917.—An slight earthquake was reported from Buenos Aires on the night of July 26-27, but without any details.

Terceira Island, Azores, August, 1917.—Several sharp earthquake shocks were felt in Ilha Terceira, Azores Islands, in the latter part of July and the early part of August. The exact dates and hours were not reported. No damage was done.

Bogotá, Colombia, August-September, 1917.—Official dispatches sent from Bogotá, Colombia, state that earthquake shocks were felt at that place intermittently from August 29th up to September 13th. Three hundred buildings are said to have been destroyed or damaged, and many persons were killed.

San José, California, September 12, 1917.—A slight shock was felt at 550 South Sixth street, San José, at 2:28 or 2:29 a. m., on September 12, 1917. The usual earthquake motions were followed or terminated by two or three short definite purses or jolts of considerable intensity.—F. J. Rogers.

San Francisco, California, September 12, 1917.—One observer reports a light shock at 3:25 a. m., on September 12th. It is said to have lasted three or four seconds, and to have had an intensity of about IV of the R.-F. scale.

Stanford University, California, September 24, 1917.—A light shock was felt at Stanford University, California, about 1:20 p. m., on September 24, 1917. It was distinctly felt by persons at rest, but not by persons in motion. It had an intensity of about III, and lasted fifteen seconds.

A CORRECTION

Dr. Otto Klotz has kindly called attention to an error in an estimate of the work done in the San Francisco earthquake of April 18, 1906. In the Presidential Address[1] I quoted Professor Henry Fielding Reid's estimate of the work as

$$316354 \times 10^6 \text{ kilowatts}$$

and gave the equivalent of this as

$$2.36 \times 10^9 \text{ H. P.}$$

The latter figures are wrong and should be

$$424 \times 10^9 \text{ H. P.}$$

the mistake arising from multiplying by the equivalent value of one horse power 746 watts instead of dividing.

ALEXANDER MCADIE.

---

[1] *Bulletin of the Seismological Society of America*, **5**, 122.

SEISMOLOGICAL REPORTS RECEIVED

AMERICA

Denver, Colorado.—Jesuit Seismological Service, Sacred Heart College. Reports nos. 5 to 8, from May 1 to August 31, 1917.

Harvard University, Cambridge, Mass.—Record of the Seismographic Station, March 29 to April 30, and reports nos. 1 to 4, from June 1 to 30, 1917.

La Paz, Bolivia.—Boletin Sismico del Observatorio del Colegia San Calixto (PP. Jesuitas), nos. 55, 60, 61, and 1 to 4, from November 24, 1916, to January 31, 1917.

Ottawa, Canada.—Earthquake Station, Dominion Astronomical Observatory, Reports nos. 5 to 19, from May 1 to August 31, 1917.

Washington, D. C.—Seismological Bulletin of the Georgetown University, nos. 26 to 28, bis, bis, from May 1 to July 31, 1917, and compiled press dispatches for the same period.

ASIA

Zi-Ka-Wei, China.—Bulletin Sismique de l'Observatoire, nos. 3 to 6, from January 31 to April 29, 1917.

Osaka, Japan.—Seismological Bulletin of the Osaka Observatory from February 21 to July 29, 1917.

EUROPE

Barcelona, Spain.—Estacion Sismica de la Real Academia de Sciences y Artes. Reports nos. 37 to 39-A, April 1 to June 30, 1917.

Coimbra, Portugal.—Boletin Sismico do Observatorio da Universidade, nos. 2a to 4c, from March 1 to June 30, 1917.

PHILIPPINE ISLANDS

Manila, P. I.—Seismological Bulletin of the Observatory, nos. 33 to 36, and 1 to 17, from November 1, 1916, to May 31, 1917.

ROSSI-FOREL SCALE OF EARTHQUAKE INTENSITIES

I. **Microseismic shock**: recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds; the shock felt by an experienced observer.

II. **Extremely feeble shock**: recorded by several seismographs of different kinds; felt by a small number of persons at rest.

III. **Very feeble shock**: felt by several persons at rest; strong enough for the direction or duration to be appreciable.

IV. **Feeble shock**: felt by persons in motion; disturbances of movable objects, doors, windows; creaking of ceilings.

V. **Shock of moderate intensity**: felt generally by everyone; disturbance of furniture, beds. etc., ringing of swinging bells.

VI. **Fairly strong shock**: general awakening of those asleep; general ringing of house bells; oscillation of chandeliers; stopping of pendulum clocks; visible agitation of trees and shrubs; some startled persons leave their dwellings.

VII. **Strong shock**: overthrow of movable objects; fall of plaster; ringing of church bells; general panic, without damage to buildings.

VIII. **Very strong shock**: fall of chimneys, cracks in walls of buildings.

IX. **Extremely strong shock**: partial or total destruction of some buildings.

X. **Shock of extreme intensity**: great disaster, buildings ruined, disturbance of the strata, fissures in the ground, rock-falls from mountains.

The Bulletin of the
Seismological Society of America

VOL. VII DECEMBER 1917 No. 4

LOCATING SUBMARINE FAULTS

By Otto Klotz

In the paper "Velocity of L Waves" by the writer and published in the BULLETIN for June last, No. 2, Vol. VII, it was stated that "it is not unreasonable to believe that with high-class seismographs and expert readings of their records we would not only be able to obtain the average position of the epicenter but also the position and direction of the fault line itself." Since the above was written the writer has recently received from Perth, West Australia, a copy of the seismogram obtained there for the earthquake of May 1, 1915, and which was so universally recorded.

In the July-August number, 1916, of the *Journal of the Royal Astronomical Society of Canada* the writer published the position of epicenters of earthquakes for the latter half of 1914 and the whole of 1915 in which the above shock is included and the adopted epicenter was given as N. 49°, and 155°.9 E., being south of Onekotan island, off the southern extremity of the peninsula of Kamchatka, and on the margin of the Kurile Deep. It may be stated that in plotting by the stereographic method and using the Klotz Tables the intersection of the various arcs from the stations used did not all intersect exactly at the same point, however the weighted intersection had the above geographical co-ordinates. Now comes the photographic copy of the gram from Perth, a beautiful record with sharply defined *P* and *S*, and which cannot be mistaken. The only regrettable feature is that its time-scale is rather cramped, and the time marks only at the hours. But notwithstanding this slight drawback the deduced distance, 9280 km., even allowing for possible range of uncertainty due to time-scale, shows clearly that the epicenter for this gram was not as far north as given above. Combining the distances of Perth, Zi-Ka-Wei and Honolulu, the last two the nearest stations to the seismic region, we obtain an epicenter off the Island of Urup, i. e., in or along the Kurile Deep. The evidence seems irrefutable that we have an epicenter off Onekotan and one off Urup, both on or in the Kurile Deep. Re-reading and measuring on the 30-inch globe the various distances of other stations giving good records to the nearest point along the line giving the above two epicenters better accordances are secured than if we try to join them all to one point—to one epicenter. The conclusion is forced on one that we have to deal here with a break-down along a fault line 500 km. long running in a N. E.-S. W. direction, the trend of the well-known Kurile Deep, and the seat of much seismic action. Perth lies approximately on the great circle passing through the Kurile Deep. The Perth gram as read here gives P 5^h 13^m 36^s, S 5^h 24^m 00^s hence S-P 10^m 24^s equivalent to 9280 km. The deduced O is 5^h 01^m 09^s while the mean of Ottawa, Harvard, Berkeley and Eskdalemuir is 5^h 00^m 06s. There is undoubtedly an error of a minute in the Perth seismograph clock, but that does not affect the distance nor location of the epicenter. One might advance the argument that the break started at the northern end and was a minute in traveling southward the 500 km., but this will not hold as the mean of the times of Zi-Ka-Wei and Honolulu, nearer to the southern than to the northern end of the fault line, is 5^h 00^m 12^s, so that the minute clock error of Perth stands out clearly.

It is believed that this is the first instance of an attempt at locating a submarine fault. There is no reason to doubt that in time submarine faults along which seismic disturbances occur will be definitely located in all the oceans. This knowledge will have a thoroughly practical bearing on submarine cables, in determining the position of breaks, which is determined electrically by the cable itself as explained in the article "Cable Laying," pp. 404-407, by the writer in the volume, "Annals and Aims" of the Pacific Cable, 1903; and also in future cable laying in pointing out danger lines to be avoided for the cable route.

With reliable seismograms and more particularly with accurate and correct interpretation a wide panorama of interesting and valuable results looms up. The location of epicenters will expand to location of fault lines, and furthermore when our absolute times of record are reliable within a second we will have the means of following the break down from beginning to end. At present we deal with earthquakes on the assumption that it is one sudden break at a point or along the line or surface of adjustment of stresses. If this is not the case the comparison of seismograms from different stations well distributed about the seismic area will tell the story of what happened, when it happened, how and where, as well as how much energy was released in the adjustment.

It is believed that there is already a great deal of material on hand in the form of seismograms that if brought together and dealt with by a master hand would reveal much of the interior of the earth, would furnish us material for improving and extending our tables and velocity curves, so that we would reach the stage of detecting along certain paths of the seismic rays anomalies in density, elasticity and rigidity, thereby extending a helping hand to the investigator of gravity anomalies. At present co-ordination and colaboration are required.

In closing this brief note it may be pointed out that when the earthquake is one sudden breakdown, then the *O's* for all stations must theoretically be the same. But the epicenter deduced from various pairs or groups of stations will not necessarily be the same as is obvious when we consider the disturbance as occurring along a fault line of considerable extent. The *P* and *S* at each station would come from the nearest part of the fault line. It may be observed that although Galitzin was able in many instances to give from the records of one station supplied with his instruments, one with the two horizontal components and the other with vertical component, the approximate position of the epicenter, yet the offsets he has to measure on the seismogram to get the azimuth are so small that the range of the resulting position of the epicenter is much larger than the position obtained from the intersection of two arcs, by the method usually pursued. The Galitzin method was an achievement of high merit at the time, but it can not in accuracy compare with a determination made from three stations with good grams. It is hoped that this short paper will stimulate others in the analysis of the records of seismograms with the view not only of the location of epicenters but of fault lines if they participated in a seismic disturbance.

DOMINION OBSERVATORY, OTTAWA,
September 28, 1917

THE DESTRUCTION OF SAN SALVADOR

(By courtesy of *The South American* of August, 1917)

Accounts of the terrible volcanic eruption and earthquake which devastated the city of San Salvador and several adjacent towns are still so conflicting that it is difficult to ascertain just what really happened, although the disastrous results are now fairly well known.

It appears from the descriptions of eye-witnesses which are slowly coming in from Honduras and other neighboring republics that, at 7 o'clock on the evening of June 7th, Mount Jabali, a small elevation, or parasitic cone rising from the slope of the old volcano of San Salvador, slowly and terribly grew to twice its normal height, belching lava and flame from eight vents, accompanied by violent shocks of earthquake which continued for several days, completely destroying San Salvador, Santa Tecla, Armenia, Quezaltapeque and many villages.

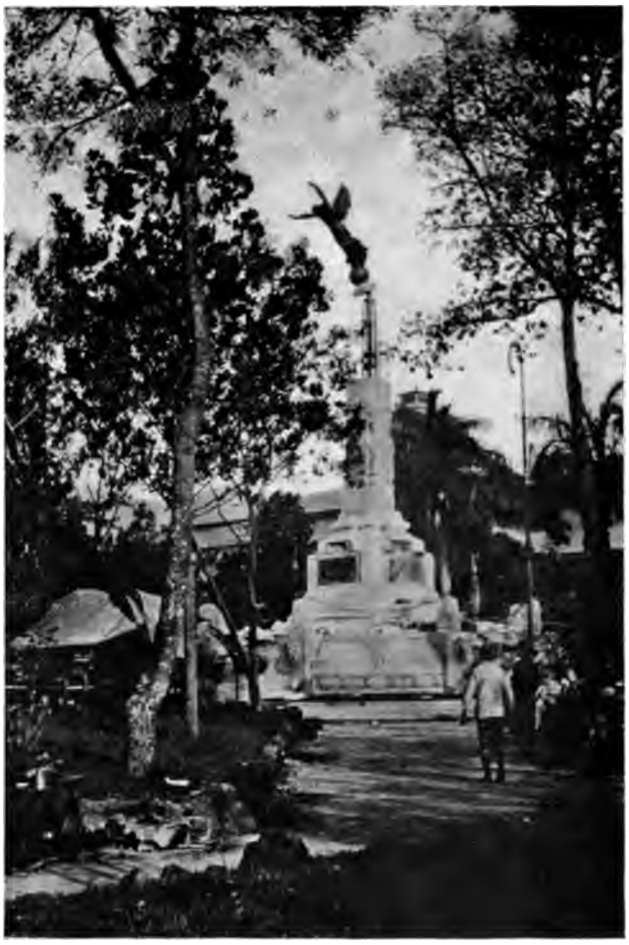
The flow of lava was towards the west, and reached the town of Armenia, inundating also the villages of Apopa and Nejapa.

This curious phenomenon is not without precedent in Salvador, where although serious volcanic eruptions in the neighborhood of the capital have not been recorded during the historic period, earthquakes have been frequent and almost as dangerous as in any region of the globe.

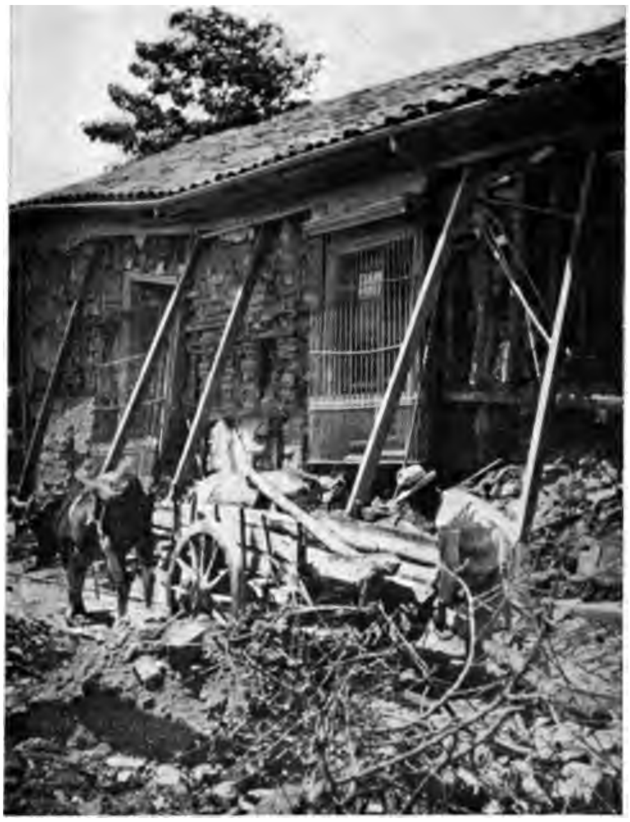
On February 23, 1770, the level ground in the neighborhood of Izalco, 45 miles west of the San Salvador volcano, suddenly opened and ejected copious lava streams. A perfectly symmetrical cone then began to rise above the surface, and continued to grow like an immense tumor of the earth until 6,000 feet in height, sending forth columns of smoke and fiery vapor at regular intervals, which at night resemble the intermittent flashes of a lighthouse.

The famous volcano of San Salvador, about six miles west of the capital, has been quiescent for more than 300 years, and the great crater, about three miles in circuit, has been flooded by a beautiful green, transparent lake 650 feet deep, around the border of which fine trees have grown to maturity.

A small colony of woodcutters has made its home on the shores of the lake, and it is to be hoped that they made good their escape before



Effect of earthquake of June 7, 1917, at San Salvador.



Destruction caused by the earthquake of June 7, 1917, at San Salvador.

the waters of the lake reached boiling point owing to the tremendous heat in the bowels of the volcano. Clouds of steam were seen to rise from the crater soon after the eruption, thus giving rise to the reports that San Salvador itself had become active after its long rest.

The city of San Salvador has been destroyed and rebuilt on the same site no less than seven times during the last three centuries, notably in 1854 and 1873. Originally founded in 1525 some distance north of its present location, it now occupies a commanding position 2,300 feet above the sea at the east foot of the volcano.

During the periods of rebuilding Santa Tecla has generally served as a refuge for the homeless people, and for this reason it is often known as Nueva San Salvador, but on this occasion Santa Tecla has suffered to an extent not less severe than San Salvador.

Heartrending accounts of the misery caused by this catastrophe are reaching us by every mail, and it is pleasant to hear that relief in the shape of money and supplies is being sent from all sides.

EARTHQUAKES AT BOGOTA, COLOMBIA

(From *The South American*, New York, November, 1917, p. 20)

During ten days, toward the end of August and the beginning of September, a long series of earthquake shocks afflicted the city of Bogota. The first news received here was extremely alarming. Besides many accidents to persons, 400 buildnigs were reported destroyed, but more detailed information by latest mails enables us to announce that the calamity, although grievous, was not so serious as at first was indicated. Of course, the moral suffering occasioned was simply dreadful. To go through ten days of continuous anguish, realizing a lack of stability and security even on the part of the earth itself, and expecting the worst at every moment, must be a horrible experience.

The first movement was noticed on Wednesday, August 29th, at 10 p. m. It was very violent and lasted some seconds. Half an hour later another, of about the same intensity but a little shorter, brought many people out of their beds to the streets, without giving them time to put on their clothes. The spectacle was fearsome and piteous, but had also a comical side. At 4 o'clock a. m., a new shake was felt, and that was all for that night.

Thursday, the 30th, passed in calm. The relief was great and found a vent through the characteristic wit of "Bogotanos," who, believing that the danger was over, made fun of the occurrences of the night before. The morning papers published humorous descriptions, and very amusing analogies were found between the earthquake and the preparations of the political parties for the next election. The dawn of the following day put an end to the joking.

At 6:30 in the morning of Friday, the 31st, the most violent earthquake ever felt in Bogota shook the city for about 15 seconds. Later on, during the day, it was repeated four times, with some decrease in intensity and duration. Almost all the buildings in the city were injured. Fortunately the greater number suffered more or less slightly, but there were many important buildings, such as the cathedral and other churches, the Rosary University, some of the government offices, and a good many private residences, which suffered very considerable damage. Total destruction, however, can be reported only in a few cases.

Loss of life occurred when a part of the beautiful chapel of Chapinero in falling killed six women. Other deaths from heart disease and nervous shock have also been charged indirectly to the earthquake. Moreover, several persons were wounded throughout the city by falling masonry as well as by their own haste and awkwardness in running away.

Consternation among the inhabitants was great. There was a general exodus to the open country, where no falling stones or beams were likely to crush the populace. The streets and public places were packed with people, and vehicles of all sorts did their best to help. The danger engendered religious feeling, and all the priests of the city were kept busy hearing confessions in boxes erected in the street, and giving absolution to legions of suddenly repentant sinners. Furthermore, as the earth trembling continued, processions and public rogatives were organized to implore divine mercy.

The city authorities, the police, and the army worked very hard to make the best of things. An active vigilance was maintained to prevent looting in the deserted houses, and efficient emergency measures were taken on behalf of the frightened populataion. As many people continued to live for days entirely out of doors, either in the parks and squares or in the surrounding country, the army placed its camp tents at the disposal of the public.

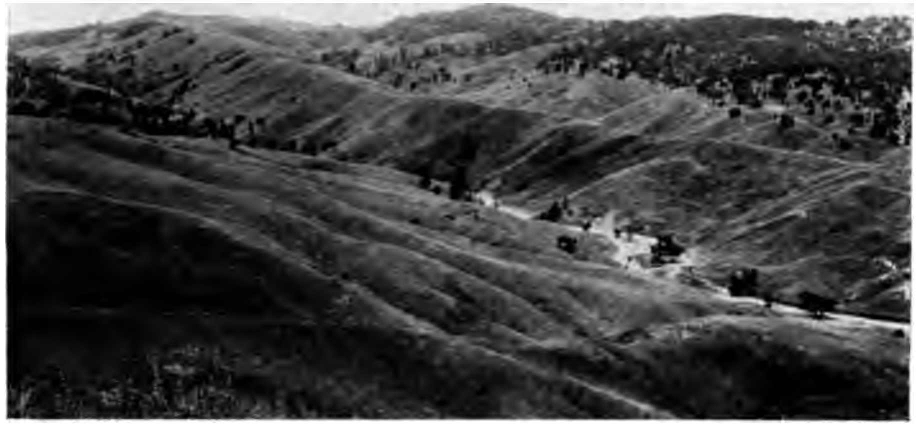
Little by little the shakes grew weaker and less frequent, until at last they ceased. Fear diminished gradually, and the danger was finally considered to be over. One by one, all have made their way back to their homes. We are very glad to say that the majority have found them easy to repair and quite comfortable even as they are, and that life, good humor and business are now going on as usual.

THE TOPOGRAPHY OF A RECENTLY ACTIVE FAULT

In the southern end of Monterey county, California, eighteen or twenty miles southwest of Coalinga, where the Tertiary rocks are faulted down against the Franciscan, there is a remarkable piece of topography produced by the faulting so intimately related to the earthquakes of that region. Dr. Ralph Arnold has kindly furnished us with a photograph showing the locality. Mr. Arnold says of the photograph:

"The view is looking south from the road leading west from the Stone Canyon coal mine. The rocks in the foreground, as I remember it, are serpentines, while the ridge is composed of Tertiary material, not so very badly broken up considering its position. There are two major faults in the zone in this particular region, one running practically along the foot of the ridge on the northeast, and the other along the foot of the ridge on the southwest. The downthrow along the fault which is followed by the stream in the middle distance is on the southwestern or far side of the fault as shown in the photograph. I think that this is one of the longest important ridges that is to be found along that part of the zone which I visited."

The photograph is reproduced on the opposite page of this number of the BULLETIN.



The Topography on the fault between Tertiary rocks on the right and Serpentines on the left, twenty miles southwest of Coalinga, California.

REVIEWS

A Brief Summary of "Les Bases de la Theorie Geologique des Tremblements de Terre." Par Le Comte F. de Montessus de Ballore, *Annales de Géographie,* XXV (1916), pp. 401-412.

This valuable article is a summary by Comte de Montessus de Ballore of the observations and facts collected during the last fifty years in regard to earthquakes, especially in regard to the relation of earth structure to earth movements. In going over the early theories in regard to the origin of earthquakes, he mentions the astral and lunar influences as factors in causing earthquakes and concludes that these ideas are inherited from ancient folk lore and are to be rejected because cosmic phenomena act over the entire earth's surface and could not develop definite seismic areas, and because differential attraction such as is exerted by the moon and sun is trivial compared with great seismic effects.

Meteorological influences also are trivial; a few millimeters of mercury in atmospheric pressure on a fault block could not move it. Moreover, the 24,000 small shocks that occur every year cannot be distributed according to any of the natural phenomena described above.

Collapse of caves has been considered by some as an important cause of earthquakes but cave regions are not in general seismic areas.

Earthquakes of volcanic origin are well known but they have different characteristics from "geologic earthquakes." Their destructive areas are limited. The amount of energy liberated by them is small in comparison with that of geologic earthquakes. Ninety per cent of the earthquakes are estimated by Comte de Montessus de Ballore to be nonvolcanic.

He gives the result of a recent work by R. P. Navarro Neuman who calculated the amount of energy liberated by certain earthquakes and compared it with that which would be developed by the engines of the great dreadnaught, Queen Elizabeth, under the hypothesis that these engines work the entire year without interruption. Using the energy generated by the Queen Elizabeth for one year as a unit, he compares the volcanic earthquake which accompanied the eruption of Sakura-jima the 12th of January, 1914, with the tectonic earthquake that occurred the 15th of June, 1911. The energy of the volcanic earthquake represents four years' work of the Queen Elizabeth, that of the tectonic, 35,000 years.

Seismic and volcanic world maps differ, at least in regard to details. The great eruptions of Krakatoa and Mt. Pele, etc., were not accompanied by earthquakes. The earthquakes of Formosa, San Francisco, Valparaiso, and Jamaica, occurred far from volcanic centers. Finally, no evidence is at hand that seismisity is decreasing in any particular area of the world but this is true in regard to vulcanism.

Comte de Montessus de Ballore takes up in detail the geologic theory of earthquakes or, as is more commonly expressed, the tectonic theory of earthquakes. Modern research has established a seismic geography, has located the regions affected by earth trembling. The seismic regions of the earth lie along lines of earth corrugation and show a linear development parallel to the high mountain ranges and ocean depths. Seismisity, in a word, is proportional to difference in relief, but the relief itself is not a cause but a charactetristic of seismic areas.

During definite geological epochs great depressions known to the geologists as geosynclines form under the slow load accumulating in the ocean bottom by sedimentation. These regions then are folded by tangential stresses and finally uplifted by vertical pressure. Such regions are characterized by pronounced seismisity, and the seismisity of any given region is a function of the tectonic accidents to which it has been subjected. In a word, the earthquakes decrease with the age of the mountains; they decrease with difference in relief of a region and with the diminution of the uplifting forces.

Seismisity is a definite criterion as to the age of a mountain range. Young chains are high because the agencies of destruction have not been long in action and the tectonic forces of elevation are not satisfied. The mountain chains of all the world show, in a parallel manner seismic instability, tectonic activity, and great absolute relief. Further, in asymmetric ranges with greater elevation on one side than the other, the steeper side is less stable in the seismic sense.

The close relation between tectonic and seismic areas is shown best in the relataion of earthquakes to faults and according to Comte Montessus de Ballore, faulting is the extreme of folding. On the other hand, great broad plateaus whose structure has not been disturbed in spite of elevation are aseismic and hence we have atability of large regions of tabular architecture and non-stability of narrow regions of folded architecture.

"Thus, observation has discovered a perfect parallelism between the magnitude of the relief, the extetnt of the vertical movements of the surface of the earth, the intensity or complexity of the tectonic happenings and, finally, the time (recentness), and seismisity. In a word, earthquakes reflect exactly the geological history and the evolution of the relief."

Comte de Ballore refers to the work of A. Rzehak for the proof that rocks are under tension and compression and snap when the stresses are relieved.

These observataions complete the proof of "the geological theory of earthquakes," and "here he (Rzehak) has surprised the demon of earthquakes in the act of committing his crime."

C. F. TOLMAN.

SEISMOLOGICAL NOTES

Memoranda of Earthquakes in Minnesota.—Professor Warren Upham of the Minnesota Historical Society at St. Paul has kindly contributed the following notes in regard to earthquakes in that state. Under date of October 19, 1917, he writes: "On September 3 (1917) at 3:30 p. m. a quake was felt upon a considerable area of central Minnesota, probably perceptibly affecting fully 10,000 or even 20,000 square miles, that is, about an eighth or a quarter of the whole state. It was most severe at Staples, a railway village and junction in the north edge of Todd county, where the shocks lasted more than 20 seconds; goods on shelves in stores were knocked down, and many windows were broken, chimneys toppled over, and concrete walks were cracked. At very closely the same time it was sensibly felt in Little Falls, Brainerd, and St. Cloud, but with little damage. In Minneapolis, 120 miles southeast from Staples, a few people noticed the shock; also about 3:30 p. m., houses trembled, pictures on the wall shook, curtains moved, and the windows rattled, and boys playing in a park 'felt the ground wiggle.' * * * As I informed our newspapers that this was the first shock known in Minnesota, in which statement our State University professor concurred, I soon received letters to correct that error. From the same Todd county, Hon. William E. Lee, its most prominent citizen, of Long Prairie, the county seat, wrote me that in his boyhood there, during 1860 or 1861, the region had an earthquake which he very distinctly remembered, 'the subject of general talk in this locality at the time.'

"Another earthquake was likewise reported in a letter from Ora J. Parker, a well known attorney of Le Sueur, on the Minnesota river nearly 50 miles southwest from St. Paul and Minneapolis, who with others distinctly felt it there, on a Sunday afternoon between 1865 and 1870. 'There was talk generally the next day of the shock.'

"These earlier earthquakes really were very mild, and were not seriously remembered and widely talked about; for the late Prof. N. H. Winchell, state geologist from 1872 to 1900, and myself as his assistant from 1879-85, also in 1893-4, failed to hear about them, so that we accounted Minnesota as historically exempt from earthquakes.

"Our newspapers generally reported the recent earthquake of September 3rd; and the accounts by Lee and Parker of the earlier shocks, about fifty years ago, as written to me, are in the *St. Paul Pioneer Press* of Sunday, September 9th, in Section II, page 8."

Two Shocks in Owens Valley, California, August 27-28.—Two earthquakes have occurred recently in the Owens Valley, in the vicinity of Bishop, California—one on August 27th at 4:40 p. m. and the other on August 28th at about 12:38 a. m.

The one on August 27th was first reported to me by John K. Schaffer, at Laws, Cal. This shock was generally felt in that region. It consisted of a twisting, choppy motion as described by this observer, and caused decided jarring of buildings, slight rattling of dishes and small articles, creaking of floors and ceilings, and decided swinging of electric lights. The duration was about ten seconds, and the shock was accompanied by a rumbling sound. The intensity is estimated to have been between IV and V of the Rossi-Forel scale.

At Bishop, Cal., three observers reported one brief shock between 4:35 and 4:40 p. m. It was generally felt in that community and caused distinct jarring and swaying of buildings, swinging of suspended lights, and the rattling of doors, windows and other loose objects. It was preceded by a rumbling sound. The intensity is estimated to have been between IV and V of the Rossi-Forel scale.

Mrs. Thomas Webb, at Big Pine, reported one shock at about 4:30 p. m. It began gradually and consisted of a trembling motion. It was generally felt, caused distinct jarring of buildings, and slight swinging of electric lights. The intensity at this point is estimated to have been about IV.

Mr. T. R. Whelan reports one shock of about three seconds' duration at 4:45 p. m., at a point ten miles west of Bishop, at Round Valley, Tungsten, Cal. It began abruptly and consisted of a rocking motion, causing distinct jarring of buildings, rattling of dishes and small articles, rattling of doors, etc., and was accompanied by underground sounds. The intensity is estimated to have been about V.

Miss Hazel L. Jones, in Round Valley, ten miles northwest of Bishop, Cal., reported an earthquake at 3:45 p. m. It began abruptly and consisted of distinct, rapid, jarring motions. She reports that there were six or eight shocks, each of about one-half second duration. The earthquake was generally felt in Round Valley, caused decided jarring of buildings, rattling of doors, windows, dishes, etc., and slight swinging of lamps. A faint rumbling sound was heard with the shocks. The intensity is estimated to have been about V.

Mrs. Alice Markert, at Benton, Cal., reports an earthquake at that place at 4:27 p. m. It was apparently felt by but verw few, and consisted of but one shock of from three to five seconds duration. The intensity is estimated to have been not higher than III.

Inquiries were sent to Kearsage, Crooked Creek Camp of the Los Angeles Bureau of Power & Light, Owenyo, Independence, Aberdeen, Manzanar, and Keeler; the replies indicate that the earthquake was not felt far to the south of Big Pine.

The earthquake of August 28th was apparently of about the same intensity as the one on the preceding day. Since it occurred in the night it was not so widely observed. It was reported, however, by the following observers: W. A. Chalfant, Bishop, Cal.; Mrs. W. F. Rood, Bishop, Cal.; Mrs. M. S. Kewley, Bishop, Cal.; Mrs. Thomas Webb, Big Pine, Cal., and John K. Schaffer, Laws, Cal.

From the data obtained it is not possible to definitely locate the epicenter of this earthquake, but it seems probable that it was in Round Valley or between that place and Bishop.—Homer Hamlin, Los Angeles, Cal.

Pacific Grove, Cal., September 1, 1917.—A slight earthquake at Pacific Grove, Cal., on September 1, 1917, at about 8 p. m. was reported by Miss Harriet Sheffield. It was felt by a few persons at rest and had a duration of about one second.—Homer Hamlin.

Owens Valley, California, Sept. 14, 1917.—A slight earthquake shock was reported by Mr. Harry W. Darling, at the Reward gold mine, on September 4, 1917. This locality is in the Owens Valley, at the western base of the Inyo Mountains, about nine miles southeast of Independence and six miles northeast of Owenyo, California. The shock occurred at 11:13 a. m., had a duration of about one second, and was felt by one person at rest.

Stanford University, California, Oct. 11, 1917.—An earthquake was felt by a few persons at rest at 1:25 p. m. on Oct. 11, 1917. It lasted about four seconds, and had an intensity of three plus of the Rossi-Forel scale.

Imperial Valley, California, Oct. 14, 1917.—A slight earthquake was felt in the Imperial Valley on October 14, 1917. The time of the shock is not stated. At Glamis, a Southern Pacific station on the mesa east of the Salton Basin, Mr. J. W. George reports a short, abrupt, rocking shock felt by persons at rest and accompanied by a heavy rumbling. This observer also states that it was reported that a slight shock was felt at Calexico on this date and that a loud rumbling was heard there also.

A. P. Messenger reports that this shock was felt at a point three and a half miles east of Heber, California. It was a rapid, rocking shock and was felt by everyone. It caused slight creaking of buildings and was preceded and accompanied by loud rumbling sounds. This earthquake was not reported from Niland or other points to the north. —Homer Hamlin.

Imperial Valley, California, Oct. 16, 1917.—An earthquake was felt in the Imperial Valley on October 16, 1917, at about 3:50 p. m. At Niland, California, there was a slight shock that began gradually, consisted of a trembling motion, and lasted a few seconds, as reported by Mr. E. W. Tuttle.

At Holtville, California, Earl C. Brooks reports a shock at 3:50 p. m., beginning gradually and consisting of a trembling motion. It was felt by two persons standing on a cement floor; it jarred buildings, and a rumbling sound was heard before and during the shock, which lasted several seconds. It is also said to have been noticed by persons walking. Mrs. M. Slater Messenger reports that a shock was felt three and a half miles east of Heber, California, at 3:48 p. m. There was one shock of seven seconds duration, felt generally by all in the Imperial Valley. It began gradually and consisted of a rocking motion, causing decided jarring of buildings; it was preceded by loud underground sounds.

C. N. Perry reports that this shock was noticed at Calexico, California, at 3:50 p. m., where it began gradually, consisted of a trembling motion, and lasted about five seconds. It was felt generally by everyone and caused slight jarring of buildings. No underground sounds were noticed at Calexico. This shock does not seem to have been felt at Brawley, California.—Homer Hamlin.

Santa Clara Valley, California, Oct. 26, 1917.—An earthquake was generally felt throughout the Santa Clara valley and on the San Francisco peninsula by persons at 1:20 a. m., Oct. 26, 1917. It lasted four seconds, and had an intensity of three plus of the Rossi-Forel scale.

Activity of Lassen Peak, Dec. 12, 1917.—At 5:30 a. m. on Dec. 12, 1917, Lassen Peak, in northern California, renewed its volcanic activities. Large volumes of black smoke arose from the crater to a great elevation and drifted southward over the Sacramento valley.

Distant Earthquakes, Dec. 22, 1917.—Press dispatches report that an earthquake was recorded at the observatory at Vancouver, B. C., beginning at 10:06 a. m. on Dec. 22. The vibrations continued several minutes.

At Canisius College, Buffalo, N. Y., a distinct shock was recorded beginning at 1 :19 p. m. and lasting until 1 :37 p. m.

Guatemala, December 25-31, 1917.—Press dispatches from San Salvador tell of the destruction of a large part of the city of Gautemala by a series of earthquakes that began on Christmas day and continued until December 31, 1917. Cracks opened in the streets, and it is estimated that about forty per cent. of the houses have been destroyed or seriously damaged. The Colon theatre collapsed while filled with people; school buildings, churches, asylums, hospitals, sugar mills, post-office, railway station and British and American legation buildings were thrown down and many of the occupants killed or injured. The water mains of the city were broken, and the sanitary condition of the city is bad. The electric plant was damaged, and put out of commission; railway communications were interrupted. The latest reports say that though the material damage has been large, there has been no great loss of life, and that order is being maintained. Many thousands of the inhabitants are homelesss.

SEISMOLOGICAL REPORTS RECEIVED

AMERICA

Denver, Colorado.—Jesuit Seismological Service, Sacred Heart College. Reports Nos. 9 and 10, from September 1 to October 31, 1917.

Ottawa, Canada.—Earthquake Station, Dominion Astronomical Observatory, Reports Nos. 20 and 21, from September 1 to October 31, 1917.

Washington, D. C.—Seismological Bulletin of the Georgetown University, Nos. 29 to 31, from August 1 to October 31, 1917, and compiled press dispatches from June 24 to September 24, 1917.

ASIA

Za-Ka-Wei, China.—Bulletin Sismique de l'Observatoire, Nos. 7 to 12, from April 29 to August 14, 1917.

Osaka, Japan.—Seismological Bulletin of the Osaka Observatory from July 30 to August 30, 1917.

EUROPE

Barcelona, Spain.—Estacion Sismica de la Real Aacdemia de Sciences y Artes. Reports Nos. 40 to 42, July 1 to September 30, 1917.

Coimbra, Portugal.—Boletin Sismico do Observatorio da Universidade, Nos. 5 (a) to 6(b), July 1 to September 30, 1917.

PHILLIPINE ISLANDS

Manila, P. I.—Seismological Bulletin of the Observatory, Nos. 18 to 24, from June 1 to July 31, 1917.

MINUTES OF THE MEETING OF THE BOARD OF DIRECTORS OF THE SEISMOLOGICAL SOCIETY OF AMERICA

December 11, 1917

Present, Messrs. Branner, Tolman, Campbell.

Secretary Townley was unavoidably prevented at the last minute from attending.

Upon motion duly made and seconded the following named persons were elected to membership in the Society:

James E. Crombie: Dyce, Aberdeenshire, Eng.
F. L. Hoffman: Newark, N. J.
E. E. Prowell: Phoenix, Ariz.
Roland Young: Fillmore, Cal.
Amherst College Library: Amherst, Mass.
Library of the State University of Iowa: Iowa City, Ia.

The following resignations of members were accepted:

Anastasio Alfaro: Costa Rica.
Wallace W. Atwood: Cambridge, Mass.
J. C. L. Fish: Stanford University, Cal.
Luther Wagoner: San Francisco, Cal.
B. K. Emerson: Amherst, Mass.
G. F. Kay: Iowa City, Ia.

The following names of deceased members were removed from the list:

Richard E. Call: New York, N. Y.
John T. Fogarty: San Francisco, Cal.
R. H. Loughridge: Berkeley, Cal.
George W. Riter: Salt Lake City, Utah.

Five members were dropped on account of non-payment of dues.

A nominating committee was appointed as follows: G. D. Louderback, J. A. Taff, H. W. Turner, E. L. Davis, A. H. Palmer.

The following board of elections was appointed: R. S. Holway, Bernard Benfield, F. V. Cornish, D. S. Richardson, Albert Burch.

The secretary was requested to inform the secretary of the Pacific Division, American Association for the Advancement of Science, that the Seismological Society of America expects to hold a meeting in Pasadena on March 29-30, at the time of the Pacific Division's meeting.

The secretary was requested to inform President Woodworth that he had all necessary authority to arrange for a meeting of the Seismological Society in Pittsburg at the time of the meeting of the American Association for the Advancement of Science if such meeting seemed desirable.

The librarian of the State Library in San Francisco requested the Seismological Society to deposit a complete set of its publications. The decision was in the negative, inasmuch as bound volumes of the publications are to be found in existing San Francisco libraries.

Dr. Branner reported that he would attend a meeting of engineers in Los Angeles in the near future and would take advantage of the opportunity to further the interests of the Seismological Society.

W. W. Campbell, *Secretary pro tem.*

MEMBERS OF THE SEISMOLOGICAL SOCIETY OF AMERICA

December 1, 1917

Adams, Frank D. . . . . McGill University, Montreal, Canada
Aguilera, José G. . . . . Mexicali, Mex.
Ahern, M. J. (S. J.) . . . . Boston College, Chestnut Hill, Mass.
Anderson, Robert Van Vleck . . . . Menlo Park, Cal.
Arnold, Ralph . . . . 821 Union Oil Bldg., Los Angeles, Cal.
de Ballore, Count de Montessus, Servicio Sismolojico, Santiago, Chile
Barbour, Edwin H. . . . . University of Nebraska, Lincoln, Neb.
*Bascom, Florence . . . . Bryn Mawr College, Bryn Mawr, Pa.
Bauer, L. A. . . Dept. Terrestrial Magnetism, 36th St. and Broad Branch Road, Washington, D. C.
Beeson, J. J. . . . . Alta, Utah
Benfield, Bernard . . . . Rialto Bldg., San Francisco, Cal.
Benson, Oscar A. . . . . Albert City, Iowa
Berloty, B. (S. J.) . . Observatoire de Ksara, Saadnail par Beyrouth, Syrie
Bicknell, Ernest P. . . . . . 715 Union Trust Bldg., Washington, D. C.
Bingham, A. C. . . . . 218 Fifth St., Marysville, Cal.
Biolley, P. . . . . Apart. 519, San José, Costa Rica
Blackshear, Edward L. . . . Prairie View College, Prairie View, Tex.
Blain, J. (S. J.) . . St. Boniface College, St. Boniface, Manitoba, Can.
*Blanding, Gordon . . . . Belvedere, Cal.
Blaney, Chas. D. . . . . Saratoga, Cal.
*Board of Fire Underwriters of the Pacific, 914 Merchants Exchange Bldg., San Francisco, Cal.
Boggs, Edward M. . . . . Box 496, Oakland, Cal.
Boutwell, John M. . . . . 1323 De la Vina St., Santa Barbara, Cal.
Brackett, Frank P. . . Pomona College Observatory, Claremont, Cal.
Branner, George C. . . . . 5239 Cornell Ave., Chicago, Ill.
*Branner, J. C. . . . . Stanford University, Cal.

---

*Life member.

Branscomb, J. H.................122 W. Granite St., Butte, Mont.
Brasch, Frederick E.............John Crerar Library, Chicago, Ill.
Brennan, J. F....................Kingston, Jamaica, West Indies
Brooks, C. F......................Yale Station, New Haven, Conn.
Brown, Chas. W.................37 Barnes St., Providence, R. I.
Brown, E. Call..............Sierra Madre Club, Los Angeles, Cal.
Brownhill, J. S...........................Negril P. O., Jamaica
Bryan, Barnabas....................Box 387, Caracas, Venezuela
Burbank, Luther.............................Santa Rosa, Cal.
Burch, Albert..................Crocker Bldg., San Francisco, Cal.
Butler, G. Montague.........University of Arizona, Tucson, Ariz.
Campbell, Douglas H..................Stanford University, Cal.
Campbell, Leon..Harvard College Observatory, Cambridge, Mass.
Campbell, W. W............Lick Observatory, Mt. Hamilton, Cal.
Carlsmith, Carl Schurz..........................Hilo, Hawaii
Carney, Frank.................................Granville, O.
de Carvalho, Anselmo Ferraz..Faculdade de Sciences, Universidade Coimbra, Portugal.
Cebrian, J. C................1801 Octavia St., San Francisco, Cal.
Chamberlin, Rollin T..........University of Chicago, Chicago, Ill.
Chamberlin, T. C..............University of Chicago, Chicago, Ill.
Chauvet, A. L....................702 Sixtieth St., Oakland, Cal.
Chu, C. C. ....12 Sumner Road, Cambridge, Mass.
Cirera, Ricardo (S. J.)...........................Tortosa, Spain
Clapp, Frederick G. ....120 Broadway, New York, N. Y.
Cleland, Herdman F.......Williams College, Williamstown, Mass.
Clemens, Carl..............................Snohomish, Wash.
Cobb, Collier..............................Chapel Hill, N. C.
Coleman, A. P........School of Science, Toronto, Ontario, Canada
*Commercial Union Assurance Co. Ltd., 558 Sacramento St., San Francisco, Cal.
Cooke, Henry M. A., The Ooregum Mining Co. of India, Ltd., Oorgaum, Province of Mysore, India.
Cornish, Frank V...........Underwood Bldg., San Francisco, Cal.
Costa, José.....................1926 Pine St., San Francisco, Cal.
Crandall, Roderic.............604 Tennyson Ave., Palo Alto, Cal.
Crook, A. R............Curator of State Natural History Museum, Springfield, Ill.
Crosby, W. O.......Mass. Institute of Technology, Boston, Mass.
Crothers, George E................City Hall, San Francisco, Cal.

Cummings, Byme.......University of Utah, Salt Lake City, Utah.
Cushing, Chas. S....821 First Natl. Bank Bldg., San Francisco, Cal.
*Daly, R. A..................23 Hawthorn St., Cambridge, Mass.
Dana, Edward S............................New Haven, Conn.
David, T. W. Edgeworth, University of Sydney, N. S. W., Australia
Davis, E. F.....Bacon Hall, University of California, Berkeley, Cal.
De Golyer, Everette...............32 Broadway, New York, N. Y.
Denison, F. Napier......................Box 1200, Victoria, B. C.
Derleth, C., Jr.............University of California, Berkeley, Cal.
Dick, Frederick J.............................Point Loma, Cal.
Dole, A. R....................................Hammonton, Cal.
Dole, Chas. S...................................Lihue, Hawaii
*Drake, N. F...........University of Arkansas, Fayetteville, Ark.
Dunn, Orrin W.................Box 104, Stanford University, Cal.
Durand, W. F.........................Stanford University, Cal.
Du Val, W. S...914 Merchants Exchange Bldg., San Francisco, Cal.
Eddy, A. J........................2630 Fulton St., Berkeley, Cal.
Eells, Charles P...............2415 Pierce St., San Francisco, Cal.
Ehrenfeld, Frederick.....College Hall, Univ. Pa., Philadelphia, Pa.
Einarsson, Sturla...................Faculty Club, Berkeley, Cal.
Emerson, F. V......Louisiana State University, Baton Rouge, La.
Everette, Willis Eugene..3512 South Eleventh St., Tacoma, Wash.
Fenner, Clarence N...Geophysical Laboratory, Washington, D. C.
Finlay, George I...........New York University, New York, N. Y.
Fisher, George J..................................Coyote, Cal.
Fletcher, Chas. R............402 Stimson Bldg., Los Angeles, Cal.
Forbes, John F.................Crocker Bldg., San Francisco, Cal.
Forstall, A. W. (S. J.)..College of the Sacred Heart, Denver, Colo.
Fowler, F. H..................221 Kingsley Ave., Palo Alto, Cal.
Franklin, E. C..........................Stanford University, Cal.
Franklin, W. S.............................South Bethlehem, Pa.
*Fuller, M. L..............134 West Upsal St., Germantown, Pa.
Gama, Alipio..Rua Curuzu, No. 58, Sao Christovao, Rio de Janeiro, Brazil.
Gauthier, H. (S. J.)..Observatoire de Zi-Ka-Wei, Shanghai, China
von Geldern, Otto...........865 Pacific Bldg., San Francisco, Cal.
George, R. D.....................845 Eleventh St., Boulder, Colo.
*Gilbert, G. K..............Geological Survey, Washington, D. C.
Gilman, C. E.......................851 Calmar Ave., Oakland, Cal.
Glenn, L. C..............Vanderbilt University, Nashville, Tenn.

Gordon, Adam R....................San Juancito, Honduras, C. A.
Gordon, C. H...........University of Tennessee, Knoxville, Tenn.
Gould, Chas. N.......Oklahoma Geological Survey, Norman, Okla.
Grant, Joseph D...............2200 Broadway, San Francisco, Cal.
Grasty, John S.........University of Virginia, Charlottesville, Va.
Green, J. W........U. S. Coast and Geodetic Survey, Sitka, Alaska
Gunn, James A., Jr..............................Kelseyville, Cal.
*Haarmann, Erich.............Apartado No. 1408, Mexico, D. F.
Haehl, H. L.......1315 Humboldt Bank Bldg., San Francisco, Cal.
Hall, Maxwell................Montego Bay, Jamaica, West Indies
Hamlin, Homer............1021 S. Union Ave., Los Angeles, Cal.
Hassan, Ali A.............203-204 Riggs Bldg., Washington, D. C.
Henderson, Chas. W..........409 New P. O. Bdlg., Denver, Colo.
Herrmann, F. C................375 Sutter St., San Francisco, Cal.
Hershey, Oscar H...............................Kellogg, Idaho
Hicks, A. R...................................Twin Falls, Idaho
Hills, Thomas M...................1942 Inka Ave., Columbus, O.
Hitchcock, C. H.................2376 Oahu Ave., Honolulu, T. H.
Hobbs, Wm. H.........University of Michigan, Ann Arbor, Mich.
Hoffman, F.L...Prudential Insurance Co. of America, Newark N. J.
Holmes, Howard C............112 Market St., San Francisco, Cal.
Holway, R. S.....8 Bacon Hall, Univ. of California, Berkeley, Cal.
Hook, J. S....................Marland Oil Co., Ponca City, Okla.
Hoover, H. C................................Washington, D. C.
Hoover, Mrs. Lou Henry...............Stanford University, Cal.
Hoskins, L. M...................365 Lincoln Ave., Palo Alto, Cal.
Hovey, E. O.....Amer. Museum of Nat. History, New York, N. Y.
Howe, Ernest...............77 Rhode Island Ave., Newport, R. I.
Huerta, Santiago de la.....Univ. Nacional de Cuba, Habana, Cuba
*Hussey, William J.....University of Michigan, Ann Arbor, Mich.
*Jacobitti, Eugenio.................................Bari, Italy
Jaggar, T. A., Jr...Hawaiian Volcano Observatory, Volcano House, Hawaii
Jamison, C. E.....................P. O. Box 1300, Billings, Mont.
Jenkins, O. P..........................Stanford University, Cal.
Jenkins, Olaf P......State College of Washington, Pullman, Wash.
Johnston, A. W........Dept, of Geology, University of Minnesota, Minneapolis, Minn.
Jones, J. C.....................University of Nevada, Reno, Nev.
Jung, A. M.................Ganzaga University, Spokane, Wash.

Keen, W. W..................1729 Chestnut St., Philadelphia, Pa.
Keesling, Francis V......1205 Chronicle Bldg., San Francisco, Cal.
Kellogg, V. L..........................Stanford University, Cal.
Kemp, J. F................Columbia University, New York, N. Y.
Keyser, E. M................U. S. Weather Bureau, Portland, Ore.
Kimball, E. B.................284 Mountain Ave., Piedmont, Cal.
Klotz, Otto.......................437 Albert St., Ottawa, Canada
Knecht, C. E.........Box 2269, Johannesburg, Transvaal, S. Africa
Koster, F. J...............22d and Illinois St., San Francisco, Cal.
Kroeck, L. S.................College of the Pacific, San Jose, Cal.
Lampland, Carl O............Lowell Observatory, Flagstaff, Ariz.
Laughlin, Homer, Jr.........666 West 28th St., Los Angeles, Cal.
Lawrence, Samuel C................7 Rural Ave., Medford, Mass.
Lawry, Geo. V...........1116 Boston Block, Salt Lake City, Utah
Lawson, A. C..............University of California, Berkeley, Cal.
Ledyard, B. C.............Garden City Bank Bldg., San Jose, Cal.
Lees, James H.....................State House, Des Moines, Ia.
Leib, S. F.......................................San Jose, Cal.
Lemos, Alix Correa..National Observatory, Rio de Janeiro, Brazil
Lenox, Lionel R........................Stanford University, Cal.
Leuschner, A. O..................1816 Scenic Ave., Berkeley, Cal.
Lewis, Robert S..........University of Utah, Salt Lake City, Utah
Libbey, Wm....................................Princeton, N. J.
Lietz, Adolph............632 Commercial St., San Francisco, Cal.
Lindley, Curtis H.............604 Mills Bldg., San Francisco, Cal.
*Lisboa, M. A. R.....426 Praia de Botafogo, Rio de Janeiro, Brazil
Lisson, Carlos I...........Casilla de Correos, No. 787, Lima, Peru
Loring, Conrad.............1063 Flood Bldg., San Francisco, Cal.
Loring, Frank C.........Home Life Bldg., Toronto, Ontario, Can.
Louderback, Geo. D........University of California, Berkeley, Cal.
Lynch, Edward................R. D. No. 1, 365 A, Pasadena, Cal.
McAdie, Alex. G..........Blue Hill Observatory, Readville, Mass.
McCallie, S. W....................................Atlanta, Ga.
MacCarthy, Marion S...............2045 Birch St., Denver, Colo.
McCaughern, Thos...914 Merchants Ex. Bldg., San Francisco, Cal.
McCune, Jas. N..........................Box 745, Portland, Ore.
McLaughlin, A. C..............65 Market St., San Francisco, Cal.
Maddrill, James D...U. S. Bureau of Efficiency, Washington, D. C.
Mahoney, Daniel P. (S. J)...College of the Holy Cross, Worcester, Mass.

Marsters, V. F................316 Rialto Bldg., Kansas City, Mo.
Marvin, C. F...........U. S. Weather Bureau, Washington, D. C.
Masó, Miguel Saderra (S. J.)...........Observatory, Manila, P. I.
Mather, Kirtley F............School of Mining, Kingston, Ontario.
Mathewson, R. H...........2563 Buena Vista Way, Berkeley, Cal.
Mendenhall, W. C.....U. S. Geological Survey, Washington, D. C.
Menke, J. H. Jr. ....Maricopa, Cal.
Merritt, F. C..............1202 Garden St., San Luis Obispo, Cal.
Middleton, H. L.............................Boulder Creek, Cal.
Miller, Benj. L...........Lehigh University, South Bethlehem, Pa.
Miller, Dayton C.....Case School of Applied Science, Cleveland, O.
Miller, Irving...............2942 Claremont Blvd., Berkeley, Cal.
Mitchell, C. W., 914 Merchants Exchange Bldg., San Francisco, Cal.
Mitchell, Walter M...........112 North 34th St., Philadelphia, Pa.
*Moffit, J. K..............First National Bank, San Francisco, Cal.
Moore, David C...............38-40 Pacific Ave., Santa Cruz, Cal.
Moore, E. S...................................State College, Pa.
Moran, Robert B.......520 Union League Bldg., Los Angeles, Cal.
Morgan, Percy Gates..Geological Survey Office, Wellington, N. Z.
Morize, Henrique....Observatorio Nacional, Rio de Janeiro, Brazil
Mulholland, Wm............Box 618, Station C, Los Angeles, Cal.
Naramore, Chester..........Bureau of Mines, Washington, D. C.
Negri, Galdino....Observatorio Astronomico, La Plata, Argentina
Newsom, J. F...........................Box 563, Palo Alto, Cal.
Nickel, J. Leroy..............................Menlo Park, Cal.
Nolan, Edward J...Academy of Natural Sciences, Philadelphia, Pa.
Ochsner, W. H..............713 Hobart Bldg., San Francisco, Cal.
Odenbach, F. L. (S. J.).........St. Ignatius College, Cleveland, O.
Ogilvie, Ida H.................Barnard College, New York, N. Y.
O'Hara, Cleophas C...South Dakota School of Mines, Rapid City, S. D.
Ohern, D. W.................................Norman, Okla.
de Oliveira, Euzebio Paulo......Servico Geologico, Ministerio da Agricultura, Rio de Janeiro, Brazil
Olney, Warren, Jr...1107 Merchants Ex. Bldg., San Francisco, Cal.
Orcutt, W. W.............1328 West Fifth St., Los Angeles, Cal.
Ordonez, Ezequiel.........2a General Prim 43, Mexico City, Mex.
Osborne, Clarence B...care Calif. Highway Commission, Forum Bldg., Sacramento, Cal.
Osborne, H. Z., Jr........City Engineer's Office, Los Angeles, Cal.

O'Shaughnessy, M. M.........2732 Vallejo St., San Francisco, Cal.
Pack, Frederick J........University of Utah, Salt Lake City, Utah
Packard, Henry J...............420 Eddy St., San Francisco, Cal.
*Page, Charles....Merchants Exchange Bldg., San Francisco, Cal.
Palmer, Andrew H...U. S. Weather Bureau, 1500 Merchants Exchange Bldg., San Francisco, Cal.
Parkin, Wm. M.................5577 Hampton St., Pittsburg, Pa.
Pearce, L. F......................San Juancito, Honduras, C. A.
Peck, Frederick B.................Lafayette College, Easton, Pa.
Pemberton, J. R............71 Clarendon Ave., San Francisco, Cal.
Perry, C. N..........................P. O. Box A1, Calexio, Cal.
Perry, H. F.............................Box 263, Palo Alto, Cal.
Phelan, James D................Phelan Bldg., San Francisco, Cal.
Phillips, Wm. B..................School of Mines, Golden, Colo.
Pirsson, L. V.................41 Trumbull St., New Haven, Conn.
Pratt, Wallace E...................Box 983, Wichita Falls, Tex.
Prouty, Wm. F..........Department of Geology, University, Ala.
Prowell, E. E.....Parke de la Sierra, R. F. D. No. 5, Phoenix, Ariz.
Purdue, A. H............State Geological Survey, Nashville, Tenn.
Ralstan, Ivan R.....................P. O. Box 444, Calexico, Cal.
Reed, Wm. G...........U. S. Weather Bureau, Washington, D. C.
Reeds, Chester A...American Museum of Natural History, 77th St. and Central Park West, New York, N. Y.
Reid, H. F.............Johns Hopkins University, Baltimore, Md.
Ricard, Jerome S. (S. J.)....Univ of Santa Clara, Santa Clara, Cal.
Rice, John A..................525 Market St., San Francisco, Cal.
Rice, Wm. North............................Middletown, Conn.
Richardson, D. S...128 Lick Bldg., 25 Montgomery St., San Francisco, Cal.
Ries, Heinrich..................Cornell University, Ithaca, N. Y.
Rixford, Emmet...........1795 California St., San Francisco, Cal.
Rizso, G. B.........................Osservatorio, Messina, Italy
Roberts, Milnor........4505 Fifteenth Ave., N. E., Seattle, Wash.
Robertson, G. M.....914 Merchants Ex. Bldg., San Francisco, Cal.
Rocha, Dias da.....................Museu Rocha, Ceará, Brazil
Rogers, F. J...........................Stanford University, Cal.
Rohani Thiurnal Raja..Kighakke Kottaram Palace, Trivandrum, Travancore, S. India
Rolfe, F.....................1631 Council St., Los Angeles, Cal.
Ross, G. McM................444 West Poplar St., Stockton, Cal.

Rowley, R. L.....Board of Fire Underwriters of the Pacific, 914 Merchants Exchange Bldg., San Francisco, Cal.
Roxo, Mathias, de Oliveira..Servico Geologico, Ministerio de Agricultura, Rio de Janeiro, Brazil
Runyon, C. F................589 Market St., San Francisco, Cal.
Ryan, Harris J.........................Stanford University, Cal.
*Sayles, Robert W........263 Hammond St., Chestnut Hill, Mass.
Scherer, J...........................Port-au-Prince, Haiti, W. I.
Schrader, Gustave......................Box 72, Sutter Creek, Cal.
Schutt, R............Papenhuderstrasse 8, Hamburg 24, Germany
Schwennesen, A. T.....................Box 930, Cheyenne, Wyo.
Scofield, D. G.............Standard Oil Bldg., San Francisco, Cal.
Scott, A. H................Lovelock Assay Office, Lovelock, Nev.
Searle, Geo. M. (C. S. P.)...660 California St., San Francisco, Cal.
*See, T. J. J...........U. S. Naval Observatory, Mare Island, Cal.
Shattuck, George B..........Vassar College, Poughkeepsie, N. Y.
Shedd, Solon...................................Pullman, Wash.
Sheldon, Pearl G...................Cayuga Heights, Ithaca, N. Y.
Shepard, E. M.................1403 Benton Ave., Springfield, Mo.
Shutts, Arthur B............................Poultney, Vermont
Sidgreaves, Walter (S. J.)..Stonyhurst College Observatory, near Blackburn, Eng.
Small, H. L.......................................Poultney, Vt.
Smith, Burnett..............Syracuse University, Syracuse, N. Y.
Smith, B. J.........................641 Vernon St., Oakland, Cal.
Smith, Geo. Otis......U. S. Geological Survey, Washington, D. C.
Smock, John C.................................Hudson, N. Y.
Snyder, Irving H.............................Los Gatos, Cal.
Soo-Hoo, Peter, Koushing Engineering Co., Howe Bldg., West Bund, Canton, China
Soper, E. K..........Oregon Agricultural College, Corvallis, Ore.
Souza, Bernardino José de................S. José 47, Bahia, Brazil
Spalding, W. A.............134 North Gates St., Los Angeles, Cal.
Speight, R................Canterbury College, Christchurch, N. Z.
Spencer, Geo. Otis, The Virginia, Rush and Ohio Sts., Chicago, Ill.
Squire, John A...........................Box 5, Palo Alto, Cal.
Stall, A. G.................1018 E. Augusta Ave., Spokane, Wash.
Stanford, Josiah W.........Warm Springs, Alameda County, Cal.
Starke, Eric A..................2655 Dwight Way, Berkeley, Cal.
Steel, Donald.......................718 Bryant St., Palo Alto, Cal.

Stevens, F. A............................Box 321, Palo Alto, Cal.
Stevenson, A. E..................20 Nassau St., New York, N. Y.
Stoy, Sam B.....................332 Pine St., San Francisco, Cal.
Sur, Forest John S.................609 Colfax Ave., Denver, Colo.
Surr, Gordon................321 Eighth St., San Bernardino, Cal.
Symington, R. B..............216 Mills Bldg., San Francisco, Cal.
*Taber, Stephen.....University of South Carolina, Columbia, S. C.
Taff, J. A.........................628 Cowper St., Palo Alto, Cal.
Taylor, Frank B............2905 Fairfield Ave., Fort Wayne, Ind.
Templeton, E. C.....................203 Park Ave., Modesto, Cal.
Thiele, F. C.....................1247 Cowper St., Palo Alto, Cal.
Tolman, C. F., Jr.......................Stanford University, Cal.
Tondorf, Francis A. (S. J.)..Seismological Observatory, Georgetown University, W. Washington, D. C.
Townley, S. D..........................Stanford University, Cal.
Townsend, Rex.....1416 Twentieth St., N. W., Washington, D. C.
Tristán, J. F.......................Box 357, San José, Costa Rica
Turner, H. W.................634 Mills Bldg., San Francisco, Cal.
Udden, Anton D..............Augustana College, Rock Island, Ill.
Uhlig, Carl.............Room 18, Ferry Bldg., San Francisco, Cal.
*Van Horn, Frank R., Case School of Applied Science, Cleveland, O.
Varney, Burton M..............139 Berkeley St., Lawrence, Mass.
*Veatch, A. C.......19 Grosvenor Gardens, S. W. 1, London, Eng.
Vickery, Frederick Paul..........367 Forest Ave., Palo Alto, Cal.
*Vietor, E. K....Imperial German Consul, Box 555, Richmond, Va.
*Volz, F. W..................................Wyandotte, Okla.
Wagner, C. F........204 Lumbermen's Bank Bldg., Portland, Ore.
Walcott, Chas. D......Smithsonian Institution, Washington, D. C.
Waldron, Richard, Jr.,..204 Citizens Nat. Bank Bldg., Los Angeles, Cal.
Waring, G. A.....................410 Clinton Bldg., Tulsa, Okla.
Warthorst, Frank W.......R. F. D. No. 2, Box 7, Bakersfield, Cal.
Watson, T. L..........University of Virginia, Charlottesville, Va.
Watt, Rolla V...............201 Sansome St., San Francisco, Cal.
Weaver, Charles E......University of Washington, Seattle, Wash.
White, Geo. F..................................Valdez, Alaska
Wigglesworth, Edward...........109 Chestnut St., Boston, Mass.
Williams, T. M...................351 Homer Ave., Palo Alto, Cal.
Willis, Bailey.........................Stanford University, Cal.
Wood, Harry O...Hawaiian Volcano Observatory, Volcano House, Hawaii.

Woodward, Robert S.....65 The Dresden Apts., Washington, D. C.
*Woodworth, J. B..........Geological Museum, Cambridge, Mass.
Wright, W. Q...................................Sausalito, Cal.
Wroth, James S......................Chuquicamata, Chile, S. A.
Young, Roland................Montebello Oil Co., Fillmore, Cal.
Zeigler, Victor...................................Golden, Colo.

SUBSCRIBERS

American Geographical Society, The......Broadway at 156th St., New York, N. Y.
American Philosophical Society, The............Philadelphia, Pa.
Amherst College Library.........................Amherst, Mass.
Augustana College and Theological Seminary, the Denkman Memorial Library of,.............................Rock Island, Ill
Boston Public Library............................Boston, Mass.
Bureau of Mines, Library of...................Toronto, Canada
California State Library.................4......Sacramento, Cal.
Chief Astronomer, Interior Department..........Ottawa, Canada
Cleveland Public Library, Order Department........Cleveland, O.
College of the Pacific............................San Jose, Cal.
Colorado School of Mines, Library of...............Golden, Colo.
Columbia University, Library of................New York, N. Y.
Congress, Library of.........................Washington, D. C.
Cornell University, Library of......................Ithaca, N. Y.
Crombie, James E......Parkhill House, Dyce, Aberdeenshire, Eng.
Dartmouth College Library......................Hanover, N. H.
Director of Agriculture..................Port-of-Spain, Trinidad
Erdmagnetisches Observatorium und Erdbeben-Station, München, O. 27, Germany
Franklin Institute, The.........................Philadelphia, Pa.
Fresno Public Library..............................Fresno, Cal.
Geological Survey, Librarian of..................Ottawa, Canada
Geophysical Laboratory.......................Washington, D. C.
Government Astronomer, Observatory, The..Melbourne, Vic., Aus.
Grosvenor Library................................Buffalo, N. Y.
Harvard College Observatory..................Cambridge, Mass.
John Crerar Library, The..........................Chicago, Ill.
Johns Hopkins University, Library of............Baltimore, Md.
Lafayette College, Library of........................Easton, Pa.

Lick Observatory..........................Mount Hamilton, Cal.
Los Angeles Public Library....................Los Angeles, Cal.
Mechanics-Mercantile Library.....57 Post St., San Francisco, Cal.
Michigan College of Mines.....................Houghton, Mich.
Minnesota Historical Society, The................St. Paul, Minn.
Mount Holyoke College, Library of..........South Hadley, Mass.
Museum of Comparative Zoology..............Cambridge, Mass.
National Geographic Magazine, 16th and M Sts., Washington, D. C.
New York Academy of Sciences, Library, care American Museum of Natural History, New York, N. Y.
New York Public Library, The..................New York, N. Y.
Northwestern University, Geological Department...Evanston, Ill.
Oakland Free Library..........14th and Grove Sts., Oakland, Cal.
Observatorio Astronómico.........................Madrid, Spain
Observatorio del Ebro.................Tortosa, Tarragona, Spain
Ohio State Library...............................Columbus, O.
Ohio State University, Library of..................Columbus, O.
Ohio Wesleyan University, Library of..............Delaware, O.
Philadelphia, Free Library of, 13th and Locust Sts., Philadelphia, Pa.
Princeton University, the Library of..............Princeton, N. J.
St. Ignatius College Library....2211 Hayes St., San Francisco, Cal.
St. Louis University, Science Library of..Grand Ave. and W. Pine Boulevard, St. Louis, Mo.
Smith College Library......................Northampton, Mass.
Smithsonian Institution, Astrophysical Observatory, Washington, D. C.
Sociedad Cientifica "Antonio Alzate"...............Mexico, Mex.
Spring Valley Water Co., Engineering Dept...375 Sutter St., San Francisco, Cal.
Sproul Observatory........Swarthmore College, Swarthmore, Pa.
State University of Iowa, Library of...............Iowa City, Ia.
Stevens, B. F., and Brown.......4 Trafalgar Square, London, Eng.
Tohoku Imperial University, Library of............Sendai, Japan
University of Arizona, Library of..................Tucson, Ariz.
University of Chicago, General Library of............Chicago, Ill.
University of Colorado, Library of.................Boulder, Colo.
University of Idaho, Library of.....................Moscow, Id.
University of Illinois, Library of...University Station, Urbana, Ill.
University of Kansas, Library of..................Lawrence, Kas.

University of Minnesota, Library of	Minneapolis, Minn.
University of Missouri, General Library of	Columbia, Mo.
University of Nevada, Library of	Reno, Nev.
University of Oregon, Library of	Eugene, Ore.
University of Pennsylvania, Library of	Philadelphia, Pa.
University of Rochester, Library of	Rochester, N. Y.
University of Texas, Library of	Austin, Texas
University of Washington, Library of	Seattle, Wash.
University of Wisconsin, Library of	Madison, Wis.
U. S. Coast and Geodetic Survey	Washington, D. C.
U. S. Geological Survey, Library of	Washington, D. C.
U. S. Weather Bureau, Library of	Chicago, Ill.
U. S. Weather Bureau, Library of	New Haven Conn.
U. S. Weather Bureau	Northfield, Vt.
U. S. Weather Bureau, Library of	San Francisco, Cal.
U. S. Weather Bureau, Library of	Washington, D. C.
Yale University Library	New Haven, Conn.

Members (Life members 23)	331
Subscribers	80
Total	411

ROSSI-FOREL SCALE OF EARTHQUAKE INTENSITIES

I. **Microseismic shock**: recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds; the shock felt by an experienced observer.

II. **Extremely feeble shock**: recorded by several seismographs of different kinds; felt by a small number of persons at rest.

III. **Very feeble shock**: felt by several persons at rest; strong enough for the direction or duration to be appreciable.

IV. **Feeble shock**: felt by persons in motion; disturbances of movable objects, doors, windows; creaking of ceilings.

V. **Shock of moderate intensity**: felt generally by everyone; disturbance of furniture, beds. etc., ringing of swinging bells.

VI. **Fairly strong shock**: general awakening of those asleep; general ringing of house bells; oscillation of chandeliers; stopping of pendulum clocks; visible agitation of trees and shrubs; some startled persons leave their dwellings.

VII. **Strong shock**: overthrow of movable objects; fall of plaster; ringing of church bells; general panic, without damage to buildings.

VIII. **Very strong shock**: fall of chimneys, cracks in walls of buildings.

IX. **Extremely strong shock**: partial or total destruction of some buildings.

X. **Shock of extreme intensity**: great disaster, buildings ruined, disturbance of the strata, fissures in the ground, rock-falls from mountains.

INDEX TO VOLUME VII

PAGE

Arnold, Ralph—The topography of a recently active fault..... 134

Ballore, Montessus de—The Mexican earthquake of November 12, 1912 31

  Les Bases de la Theorie Geologique des Tremblements de Terre, Annales de Geographie XXV (1916), pp. 401-412, review of by C. F. Tolman.......................... 135

Barcelona, Spain, seismological reports received....41, 82, 125, 143

Bases de la theorie geologique des tremblements de terre, Les, Annales de Geographie XXV (1916), pp. 401-412, by Montessus de Ballore, review of by C. F. Tolman........... 135

Bogota, Colombia, earthquakes at.......................... 132

Branner, J. C.—One of the scientific problems at our doors.... 45

  The Tejon Pass earthquake of October 22, 1916.......... 51

California earthquakes during 1916, by Andrew H. Palmer.... 1

Campbell, W. W.—Minutes of meeting of Board of Directors.. 144

Coimbria, Portugal, seismological reports received..41, 82, 125, 143

Denver, Colorado, seismological reports received...41, 82, 125, 143

Earthquakes at Bogota, from *The South American*, N. Y., November, 1917, p. 20................................ 132

Earthquakes at Almirante, Republic of Panama, in April, 1916, note on the, by Harry Fielding Reid.................... 27

Earthquake of January 30, 1917, The, by Otto Klotz.......... 34

Earthquakes in Southern and Eastern California, by Homer Hamlin 113

Earthquakes, notes and reviews concerning—

  Alcantara Maranhao, Brazil 40

  Argentine Republic 123

  Arroya Grande, California 115

  Bali, Malay Archipelago 39

  Bishop, California 72

  Bogota, Colombia 124

  Buffalo, New York 142

  Cahuilla, California 75

  Calexico, California 74, 75, 76

  Coachella, California 118

Earthquakes, notes and reviews concerning—
  Fillmore, California 40
  Formosa 38
  Guatemala 142
  Heber, California 76
  Hemet, California 38
  Imperial Valley, California 75, 140, 141
  Iowa City, Ia. 122
  Lassen Peak, California 39, 141
  Leona alley, California 37
  Los Angeles, California 39, 113, 114, 115, 117
  Los Olivos, California 117
  Minnesota 138
  Missouri 73
  Montreal, Canada 39
  Morro Velho Minas, Brazil 40
  Needles, California 74
  Ogdensburg, New York 74
  Owens Valley, California 39, 113, 115, 139, 140
  Pacific Grove, California 140
  Pt. Loma, California 122
  Rochester, Nevada 74
  Rome, Italy 123
  Samoa 123
  San Francisco, California 124
  San Jose, California 124
  San Luis Obispo, California 38
  San Miguel, California 113
  San Salvador 76
  Santa Barbara, California 74
  Santa Clara Valley, California 140
  Santa Rita, California 72
  Saugus, California 75
  Sierra Madre, California 116
  S. Thome 37
  Stanford University, California 40, 124, 140
  Tejon Pass, California 37
  Terceira Island, Azores 123
  Terni, Italy 76
  Umbria, Italy 74

Earthquakes, notes and reviews concerning—
  Unga, Alaska 122
  Vancouver, B. C. 141
  Verapaz, Guatemala 38
  Victoria, Australia 40
  Victorville, California 75
  Yacuiba, Bolivia 122
  Yuma, Arizona 74
Finch, Ruy H.—The Missouri earthquake of April 9, 1917..... 91
Galitzin, Prince Boris, by Otto Klotz 49
Harvard University, seismological reports received........82, 125
Hamlin, Homer—Earthquakes in Southern and Eastern California 113
Klotz, Otto—The earthquake of January 30, 1917............ 34
  Prince Boris Galitzin................................ 49
  Velocity of L waves.................................. 67
  Some memoranda from the chairman of the Scientific Committee 97
  Locating submarine faults............................ 127
Koto, Bunjiro—The great eruption of Sakura-jima in 1914, *Journal College of Science*, Imperial University of Tokyo, Vol. XXXVIII, Art. 3, pp. 237, review of by J. B. Woodworth 77
La Paz, Bolivia, seismological reports received..........41, 82, 125
Lemos, Alix—A new liquid damping contrivance for seismographs 18
  Um novo dispositivo de amortecimento liquido para sismographos 19
McAdie, Alexandar, a correction........................... 124
Manila, P. I., seismological reports received........41, 82, 125, 143
Masó, M. Saderra—Notes concerning the Ragang Volcano and a great earthquake in South Mindanao.................. 119
Missouri earthquake of April 9, 1917, The, by Ruy H. Finch.... 91
Mattei, A. C.—Two Santa Barbara Channel earthquakes...... 61
Mexican earthquake of November 12, 1912, The, by M. de Ballore 31
New liquid damping contrivance for seismographs, A, by Alix Lemos 18
Novo dispositivo de amortecimento liquido para sismographos, Um, by Alix Lemos.................................. 19

One of the scientific problems at our doors, by J. C. Branner.. 45
Osaka, Japan, seismological reports received.......41, 82, 125, 143
Ottawa, Canada, seismological reports received.....41, 82, 125, 143
Palmer, Andrew H.—California earthquakes during 1916...... 1
Ragang Volcano and a great earthquake in South Mindanao, notes concerning the, by M. S. Masó.................... 119
Reid, H. F.—Note on the earthquakes at Almirante, Republic of Panama, in April, 1916.............................. 27
Reviews 77, 135
Rossi-Forel Scale 44, 90, 126, 158
Sakura-jima, The great eruption of, in 1914, by Bunjiro Koto, *Journal College of Science*, Imperial University of Tokyo, Vol. XXXVIII, Art. 3, pp. 237, review of by J. B. Woodworth 77
San Salvador, the destruction of............................ 130
Santa Barbara Channel earthquakes, Two, by A. C. Mattei.... 61
Scientific Committee, some memoranda from the chairman of the, by Otto Klotz.................................. 97
Seismometric bookkeeping, A further note on, by H. O. Wood 106
Seismological notes 37, 72, 122, 138
Seismological reports received 41, 82, 125, 143
Seismological Society of America—
  Members of 146
  Minutes of meeting of Board of Directors, January 23, 1917 42
  Minutes of meeting of Board of Directors, May 16, 1917... 84
  Minutes of meeting of Society, April 7, 1917.............. 83
  Minutes of meeting of Board of Directors, December 11, 1917 144
  Officers of Society.............................Back Cover
  Report of Auditing Committee.......................... 89
  Report of Board of Election............................ 86
  Report of Secretary-Treasurer.......................... 87
South Mindanao, Notes concerning the Ragang Volcano and a great earthquake in, by M. Saderra Masó................ 119
Stonyhurst College, England, seismological reports received... 82
Submarine faults, Locating, by Otto Klotz.................. 127
Tejon Pass earthquake of October 22, 1916, The, by J. C. Branner.. 51
Tolman, C. F.—Review of article by M. de Ballore............ 135
Topography of a recently active fault, The.................... 134

Townley, S. D.—
  Report of Secretary-Treasurer 87
  Minutes of meetings 42, 83, 84
Velocity of L waves, by Otto Klotz 67
Washington, D. C., seismological reports received..41, 82, 125, 143
Wood, H. O.—A further note on seismometric bookkeeping.. 106
Woodworth, J. B.—Review of article by Prof. Bunjior Koto... 77
Zi-Ka-Wei, China, seismological reports received...41, 82, 125, 143

BULLETIN

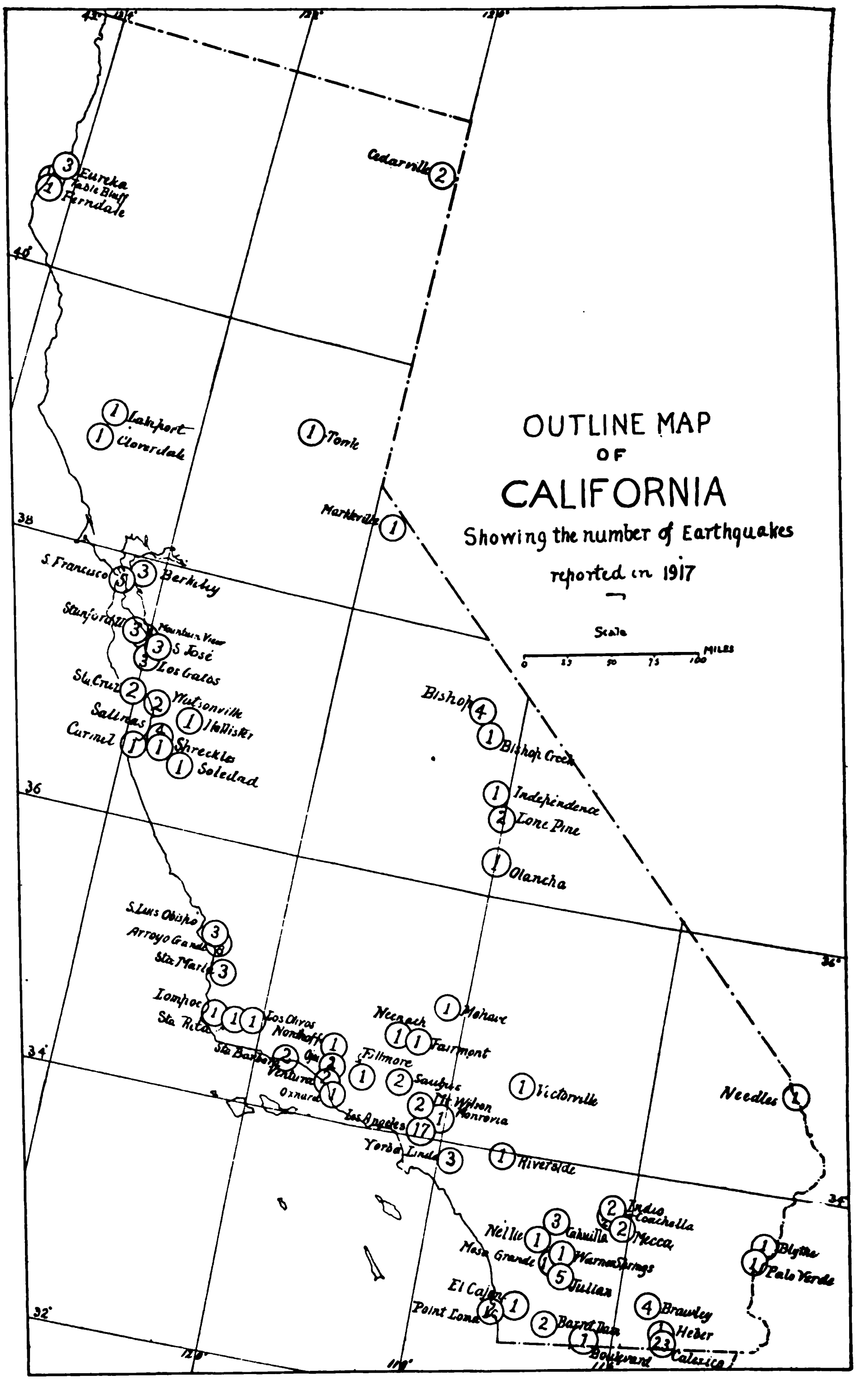
OF THE

SEISMOLOGICAL SOCIETY OF AMERICA

VOLUME VIII

1918

STANFORD UNIVERSITY, CALIFORNIA
PRINTED FOR THE SOCIETY
1918



OUTLINE MAP OF CALIFORNIA Showing the number of Earthquakes reported in 1917

The Bulletin of the
Seismological Society of America

VOL. VIII MARCH 1918 No. 1

CALIFORNIA EARTHQUAKES DURING 1917

By Andrew H. Palmer, Observer, U. S. Weather Bureau

Since July 1, 1914, the U. S. Weather Bureau has kept a record of all earthquakes which have occurred in the United States. In addition to records obtained from its own seismographs at Washington, D. C., and Northfield, Vermont, the Weather Bureau receives reports from many other institutions which have seismographs in operation. Moreover, it has the coöperation of more than four thousand voluntary observers in the securing of records of sensible earthquakes, those having an intensity of II or higher in the Rossi-Forel scale. In California the work to date has consisted chiefly of the collection of reports of earthquakes strong enough to be felt by persons. About 350 observers, well distributed throughout the state, have volunteered to coöperate in the collection of earthquake statistics. In addition, publications like the Bulletin of the Seismological Society of America and the daily press are scanned for reports of earthquakes. It is believed that few, if any, earthquakes of sensible intensity escape notice. All reports, instrumental and non-instrumental, received by the Weather Bureau are published in the *Monthly Weather Review,* an official publication.

During 1917 a total of 109 earthquakes strong enough to be felt by persons occurred in California. These alone form the basis of this discussion. This was 43, or 65 per cent, more than the number which occurred during 1916. For the third consecutive year California experienced more earthquakes than all the rest of the United States. During the past year a considerably larger number occurred during the summer dry season than during the winter wet season. From May to October, inclusive, 81, or 74 per cent of the total for the year, occurred, while during November to April, inclusive, the remaining 28, or 26 per cent, were reported. The monthly distribution was as follows:

Number of Earthquakes

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
3	4	7	7	12	29	18	9	6	7	5	2	109

Of the 109 earthquakes which occurred, 88, or 81 per cent, were so light that they were felt at one station only. The others were strong enough to be felt at two or more adjacent stations. However, at 69 different stations earthquakes were felt at some time or other during the year.

Table I is a summary of all the California earthquake reports received during 1917. The time of occurrence given is the approximate Pacific, or 120th meridian time, and the hours are numbered from 0 to 23, inclusive. Great accuracy of time is not assumed, as the time of observation recorded was, in most cases, that taken from a pocket watch or from an ordinary clock. When an earthquake was felt at a number of stations at about the same time, it is here given as though it occurred at the same minute, though that is not necessarily the case.

As in past years, more earthquakes were noted during the night than during daylight hours. During 1917 a total of 63, or 58 per cent of all, occurred between 6 p.m. and 6 a.m., while but 46, or 42 per cent, occurred during the remaining 12 hours of the day.

Figure 1 is an outline map of California showing the number of earthquakes which occurred during 1917 at the places indicated.[1] It is readily apparent from the figure that earthquakes were more frequent along the coast than elsewhere, and that they were more frequent in the southern half of the state than in the northern. While observers are relatively few in the desert regions and in the high mountains, the map probably gives a reasonably correct distribution of actual occurrences. The region of greatest seismicity was the Imperial Valley, Calexico alone having experienced 23 earthquakes during the year. The region of next greatest seismicity was that immediately south of the Sierra Madre Mountains, with a total of 17 earthquakes in Los Angeles. The region in the vicinity of Monterey Bay, which showed the highest degree of activity in California in 1916, was less active in 1917, though still worthy of note, as six shocks were noted there. San Francisco had five earthquakes, as compared with but one during the preceding year. Five occurred in the immediate vicinity of Humboldt Bay. In the Owens Valley, a recognized epicenter, eight shocks were reported during the year. In the high Sierra Nevada Mountains but one earthquake was felt, while in the

---

[1] One shock was recorded at Sierra Madre and one at Campbell, neither of which is on the map.

TABLE I. NON-INSTRUMENTAL EARTHQUAKE REPORTS, CALIFORNIA, 1917.

Day 1917	Approx. time 120th mer.	STATION	Approx. lat. (N)	Approx. long. (W)	Intensity R-F	No. of shocks	Duration Sec.	Sounds	Remarks
Jan. 12	14 42	Fairmont	34°45′	118°25′	3	1	...	None	
12	14 42	Mojave	35 03	118 12	3	1	...	None	
12	14 42	Neenach	34 47	118 37	3	1	...	None	
19	5 20	Mt. Wilson	34 13	118 16	2	1	...	None	Recorded on float raingauge
31	21 18	Santa Maria	34 58	120 28	4	2	10	None	
Feb. 9	7 28	San Jose	37 20	121 54	3	1	2	None	
9	20 30	Olancha	36 16	118 00	3	1	...	Rumbling	
13	5 05	Los Angeles	34 03	118 15	6	1	...	None	
13	5 10	Saugus	34 20	118 30	4	1	...	None	
Mar. 3	8 00	Table Bluff	40 39	124 15	6	1	11	None	Broke mantle in lighthouse
13	7 15	Salinas	36 36	122 40	3	1	...	None	
18	4 30	Lone Pine	36 37	118 01	4	1	...	None	
19	0 50	Lone Pine	36 37	118 01	4	1	...	None	Windows rattled
21	9 10	Bishop	37 22	118 24	4	1	25	Rumbling	
29	0 06	Fillmore	34 23	118 54	4	1	...	None	People awakened
29	4 59	Stanford Univ.	37 27	122 09	3	1	2	None	
Apr. 2	1 00	Berkeley	37 52	122 16	4	1	1	Rumbling	
5	11 00	Lompoc	34 38	120 29	3	1	...	None	
5	11 00	Santa Rita	34 38	120 16	4	1	...	None	Windows rattled
12	20 03	Nordhoff	34 35	119 14	5	1	2	None	Concrete tower cracked
12	20 03	Oxnard	34 12	119 08	5	3	...	None	Dishes rattled
12	20 03	Santa Barbara	34 23	119 40	6	1	...	None	Most severe in years
12	20 03	Ventura	34 17	119 17	4	2	...	None	
13	4 30	Cedarville	41 32	120 08	3	1	60	Faint	
15	22 00	Cedarville	41 32	120 08	3	1	...	None	
18	15 43	Calexico	32 41	115 30	3	2	5	Rumbling	
20	22 59	Santa Barbara	34 23	119 40	4	2	...	None	
20	22 59	Ventura	34 17	119 17	4	1	...	None	People awakened
May 11	14 36	Markleeville	38 42	119 46	5	1	...	None	
11	14 36	Towle	39 14	120 48	5	2	8	Rumbling	
17	22 06	Calexico	32 41	115 30	3	1	1	Rumbling	Sounds preceded shock
18	22 35	Yorba Linda	33 51	117 50	5	2	3	Faint	People awakened
18	23 19	Yorba Linda	33 51	117 50	4	3	3	Faint	
20	1 45	Yorba Linda	33 51	117 50	5	1	...	Rumbling	Shook buildings
24	14 00	Needles	34 50	114 36	3	1	...	None	
24	14 00	Palo Verde	33 26	114 42	3	1	...	None	
27	1 30	Brawley	32 59	115 40	5	1	...	Loud	
27	22 07	Barrett Dam	32 40	116 40	5	1	...	None	
27	22 07	Blythe	33 35	114 38	3	1	...	None	
27	22 07	Brawley	32 59	115 40	6	1	...	Loud	People frightened
27	22 07	Calexico	32 41	115 30	5	2	...	Rumbling	Lifting motion noted

TABLE I. NON-INSTRUMENTAL EARTHQUAKE REPORTS, CALIFORNIA, 1917.—*Continued.*

Day 1917	Approx. time 120th mer.	STATION	Approx. lat. (N)	Approx. long. (W)	Intensity R-F	No. of shocks	Duration Sec.	Sounds	Remarks
May 27	22 07	Coachella	33°40′	116°10′	5	2	42	None	
27	22 07	Indio	33 43	116 12	4	1	60	None	
27	22 07	Julian	33 05	116 37	5	2	20	Rumbling	
27	22 07	Mecca	33 34	116 05	5	1	...	None	
27	22 07	Mesa Grande	33 11	116 42	3	1	2	Rumbling	
27	22 07	Nellie	33 22	116 52	4	2	10	Faint	
27	22 07	Point Loma	32 43	117 15	3	1	3	None	
27	22 07	Riverside	33 58	117 21	5	1	...	None	People awakened
27	22 07	Warner Sprgs.	33 17	116 37	3	1	60	None	
27	23 05	Calexico	32 41	115 30	3	1	12	None	
28	2 17	Julian	33 05	116 37	5	1	10	Rumbling	
30	18 10	Brawley	32 59	115 40	5	1	...	None	
30	18 10	Calexico	32 41	115 30	3	2	1	Rumbling	
30	20 35	Cahuilla	33 32	116 43	5	1	4	None	
June 2	6 30	Victorville	34 32	117 18	3	1	...	None	
5	21 00	Saugus	34 20	118 30	3	1	...	None	
7	7 41	Calexico	32 41	115 30	3	1	1	None	
7	16 30	Calexico	32 41	115 30	4	1	3	Rumbling	
7	22 13	Calexico	32 41	115 30	3	2	1	Faint	
8	19 30	Carmel	36 34	121 56	4	1	...	Rumbling	
8	19 30	Salinas	36 36	121 40	3	1	10	None	Dishes rattled
8	19 30	Soledad	36 28	121 16	5	1	30	None	
10	16 20	Calexico	32 41	115 30	3	1	30	Rumbling	
10	18 13	Calexico	32 41	115 30	3	1	½	Rumbling	
10	19 54	Julian	33 05	116 37	5	1	5	Rumbling	
12	20 06	Calexico	32 41	115 30	3	1	1	Rumbling	
16	22 00	Heber	32 45	115 31	5	1	...	Rumbling	Shook buildings
18	1 55	Calexico	32 41	115 30	4	3	...	Rumbling	People awakened
18	6 21	Calexico	32 41	115 30	2	1	1	None	
21	11 20	Independence	36 49	118 13	5	1	...	None	Rocking motion
21	20 05	Julian	33 05	116 37	4	1	7	Loud	
24	12 00	Los Angeles	34 03	118 15	4	1	...	None	An abrupt bump
24	12 30	Los Angeles	34 03	118 15	4	1	...	None	
25	20 15	Los Angeles	34 03	118 15	4	1	...	None	Buildings jarred
25	20 24	Los Angeles	34 03	118 15	5	1	...	None	
26	3 51	Los Angeles	34 03	118 15	3	1	3	None	Trembling motion
26	5 26	Eureka	40 38	124 11	4	1	3	Rumbling	
26	13 15	Los Angeles	34 03	118 15	6	1	...	Rumbling	Sounds preceded shock
26	13 20	Los Angeles	34 03	118 15	6	1	...	None	Rocking motion
26	13 30	Los Angeles	34 03	118 15	6	1	...	None	Trembling motion
26	22 26	Calexico	32 41	115 30	4	1	¼	Rumbling	Noise preceded shock
28	21 50	Los Angeles	34 03	118 15	4	1	1	Rumbling	Abrupt bumping shock
28	22 25	Los Angeles	34 03	118 15	4	1	...	None	

TABLE I. NON-INSTRUMENTAL EARTHQUAKE REPORTS, CALIFORNIA, 1917.—*Continued.*

Day 1917	Approx. time 120th mer.	STATION	Approx. lat. (N)	Approx. long. (W)	Intensity R-F	No. of shocks	Duration Sec.	Sounds	Remarks
June 29	16 00	Los Angeles	34°03′	118°15′	4	1	...	None	Trembling motion
30	15 38	Los Angeles	34 03	118 15	4	5	1	Rumbling	
July 6	3 01	Owenyo	36 40	113 01	7	1	...	None	Broke aqueduct
7	12 57	San Luis Obs.	35 18	120 39	3	2	7	None	Rattled windows
7	12 57	Arroyo Grande	35 18	120 37	6	1	5	Roaring	Trembling motion
7	13 02	Arroyo Grande	35 18	120 37	6	1	5	Roaring	Trembling motion
7	13 15	Arroyo Grande	35 18	120 37	6	1	5	Roaring	Trembling motion
7	19 20	Santa Maria	34 58	120 27	3	1	10	None	
8	3 29	Arroyo Grande	35 18	120 37	4	1	...	None	Trembling motion
8	21 15	Bishop	37 24	118 26	3	1	...	Rumbling	
9	14 22	Arroyo Grande	35 18	120 37	7	1	5	Rumbling	Dishes overturned
9	14 22	San Luis Obs.	35 18	120 39	4	1	2	Loud	
9	14 38	Arroyo Grande	35 18	120 37	7	1	5	Rumbling	Rocks rolled down hillsides
9	16 43	Arroyo Grande	35 18	120 37	7	1	5	Rumbling	Chimneys damaged
9	16 45	Arroyo Grande	35 18	120 37	7	1	5	Rumbling	Trembling motion
15	11 05	Mt. Wilson	34 13	118 16	4	2	2	Rumbling	House creaked
15	11 05	Monrovia	34 08	118 00	4	1	2	Loud	Twisting motion
15	11 05	Sierra Madre	34 11	118 02	4	1	2	None	Trembling motion
15	22 50	Calexico	32 41	115 30	2	1	½	Rumbling	Sounds before shock
17	15 15	Los Angeles	34 03	118 15	4	1	...	None	Rocking motion
17	15 19	Los Angeles	34 03	118 15	4	1	...	Rumbling	Buildings swayed
17	15 30	Los Angeles	34 03	118 15	4	1	...	None	
21	8 50	Ferndale	40 35	124 16	3	3	...	None	
26	0 31	Los Olivos	34 39	120 07	4	1	25	Roaring	Trembling motion
26	0 31	San Luis Obs.	35 18	120 39	3	1	2	None	
26	0 31	Santa Maria	34 58	120 27	5	3	15	None	Moved furniture
Aug. 2	20 20	Cahuilla	33 32	116 43	4	1	3	Rumbling	
3	2 10	Los Angeles	34 03	118 15	3	1	...	Rumbling	Sounds like thunder
12	3 00	Coachella	33 40	116 10	5	1	...	Roaring	Rocking motion
18	22 00	Boulevard	32 38	116 15	3	1	1	None	
18	23 10	Julian	33 05	116 37	5	2	8	Rumbling	
27	16 35	Bishop	37 22	118 24	5	4	...	None	
28	0 40	Bishop	37 22	118 24	4	1	1	None	People awakened
28	0 40	Bishop Creek	37 15	118 17	3	1	...	None	

TABLE I. NON-INSTRUMENTAL EARTHQUAKE REPORTS, CALIFORNIA, 1917.—*Concluded.*

Day 1917	Approx. time 120th mer.	STATION	Approx. lat. (N)	Approx. long. (W)	Intensity R-F	No. of shocks	Duration Sec.	Sounds	Remarks
Aug. 31	11 20	Ojai	34°25′	119°12′	4	1	1	None	
31	12 25	Ojai	34 25	119 12	4	1	1	None	
Sept. 4	15 57	Calexico	32 41	115 30	3	1	...	None	
8	11 01	Calexico	32 41	115 30	3	2	½	Rumbling	
12	3 26	Berkeley	37 52	122 16	3	1	..	None	
12	3 26	Los Gatos	37 12	121 58	2	1	10	None	
12	3 26	Mountain View	37 23	122 05	3	1	...	None	
12	3 26	San Jose	37 20	121 54	2	1	5	None	
12	3 26	San Francisco	37 48	122 26	3	1	3	Faint	
12	3 26	Santa Cruz	36 57	122 02	2	1	3	None	
12	18 14	Eureka	40 48	124 11	4	2	...	None	Windows rattled
24	13 21	Campbell	37 17	121 57	3	1	...	None	
24	13 21	Hollister	36 50	121 20	4	1	8	None	
24	13 21	Los Gatos	37 12	121 58	3	1	15	None	
24	13 21	Salinas	36 36	121 40	3	1	5	None	
24	13 21	San Francisco	37 48	122 26	3	1	3	None	
24	13 21	Santa Cruz	36 57	122 02	4	2	4	None	
24	13 21	Stanford Univ.	37 27	122 09	3	1	15	None	
24	13 21	Watsonville	36 55	121 46	4	1	...	Faint	
25	10 34	Calexico	32 41	115 30	2	1	½	None	
Oct. 2	23 40	San Francisco	37 48	122 26	4	3	...	None	
11	13 26	Salinas	36 36	121 40	4	1	2	None	
11	13 26	Spreckels	36 35	121 38	3	1	1	Rumbling	
13	16 50	San Francisco	37 48	122 26	2	1	...	None	
16	15 50	Calexico	32 41	115 30	3	2	6	None	
22	22 00	Cahuilla	33 32	116 43	2	1	½	Rumbling	
26	1 18	Berkeley	37 52	122 16	3	2	...	None	
26	1 18	Los Gatos	37 12	121 58	4	1	8	None	
26	1 18	San Francisco	37 48	122 26	3	1	2	None	
26	1 18	San Jose	37 20	121 54	5	2	9	None	
26	1 18	Stanford Univ.	37 27	122 09	3	1	5	None	
26	19 49	Eureka	40 48	124 11	2	1	1	None	House creaked
Nov. 1	5 50	Calexico	32 41	115 30	2	1	...	None	Abrupt shock
5	1 04	Cloverdale	38 48	123 00	2	2	2	Faint	
5	1 04	Lakeport	39 02	122 56	2	2	5	Rumbling	
12	23 50	Calexico	32 41	115 30	3	1	2	Loud	
19	9 30	El Cajon	32 48	116 58	2	1	...	None	
19	9 30	Indio	33 43	116 12	4	1	30	Faint	
19	9 30	Mecca	33 34	116 05	4	2	30	Rattling	
30	22 37	Watsonville	36 55	121 46	3	1	2	Faint	Abrupt shock
Dec. 8	1 45	Calexico	32 41	115 30	4	1	5	Rumbling	People awakened
20	0 25	Barrett Dam	32 40	116 40	3	1	...	None	
20	0 25	Brawley	32 59	115 40	4	1	...	Faint	
20	0 25	Calexico	32 41	115 30	4	2	5	None	

plateau region of northeastern California two shocks were reported. On the other hand, not a single earthquake occurred during the entire year in the great interior valleys of the Sacramento and the San Joaquin Rivers,—a noteworthy fact considering the large expanse of territory and the large number of observers resident there.

INTENSITY

Since many of the earthquakes were felt at two or more adjacent stations, the reports received number more than the actual number of earthquakes, it being understood, however, that there is but one observer reporting for each individual station. Classified as to intensity, the 162 reports received during the year testified as follows: II, 14 reports; III, 55 reports; IV, 52 reports; V, 26 reports; VI, 10 reports; and VII, 5 reports. As in past years, the severest shocks did not occur at the places of most frequent disturbance. The lightest shocks were the most frequent. Of the 23 earthquakes which occurred at Calexico, all but one were of intensity IV or less.

NUMBER OF SHOCKS

But one shock accompanied most of the earthquakes. The data presented were as follows: 1 shock, 129 reports; 2 shocks, 25 reports; 3 shocks, 6 reports; 4 shocks, 1 report; and 5 shocks, 1 report. When a report of an earthquake contained no reference to the number of shocks, it was assumed that but one occurred. If more than one occurred it was believed that the observers would have been sufficiently impressed to record the fact.

DURATION OF SHOCKS

In regard to the duration of shocks the reports received during 1917 presented the following evidence: 1 second or less, 21 reports; 2 seconds, 14 reports; 3 seconds, 10 reports; 4 seconds, 2 reports; 5 seconds, 15 reports; 6-10 seconds, 14 reports; 11-20 seconds, 6 reports; 21-30 seconds, 6 reports; 31-40 seconds, none; over 40 seconds, 4 reports.

SOUNDS

Of the 162 reports received, 99, or 61 per cent, made no mention of sounds having been observed before, with or after the shocks. In the 63 cases where sounds were heard, they were described as follows: rumbling, 40 reports; faint, 11 reports; loud, 6 reports; roaring, 5 reports; and rattling, 1 report.

NOTES ON INDIVIDUAL EARTHQUAKES

While there was no earthquake of special prominence in California during 1917, a few are worthy of mention. In the order of their occurrence, these were as follows:

April 12th. At 8:03 p.m. a severe shock was felt simultaneously at Nordhoff, Oxnard, Santa Barbara, and Ventura. The intensity was estimated at IV to VI in the various places mentioned. At Santa Barbara it was the most severe in years, while at Nordhoff it was sufficiently strong to crack a concrete tower. No sounds accompanied this vibration. As these stations are situated in close proximity to the San Luis Obispo and Santa Ynez faults, the shock was probably due to movement of the crust along either or both of these.

May 11th. At 2:36 p.m. the only earthquake reported in the Sierra Nevada Mountains during the year was felt from Markleeville, Alpine County, altitude 8,000 feet, to Towle, Placer County, altitude 3,704 feet. At the former station but one shock occurred, while at the latter two distinct vibrations were felt. At both places the intensity was estimated at V. A segment of the Major Sierra fault-system traverses this region.

May 27th. The most widely felt earthquake of the year occurred at 10:07 p.m. on this date. It was preceded by a shock felt only at Brawley during the early morning of the same day, and it was followed by another one felt only at Calexico at 11:05 p.m. The shock which occurred at 10:07 p.m. was felt at 13 different stations extending entirely across southern California, from Blythe to Point Loma. Its intensity varied from III to VI. At Brawley, where it was most severe, and the first heavy shock in almost a year, it caused some walls to crack. People were frightened, and at a school where commencement exercises were in progress several women and children fainted as a result of hysteria. At four of the stations at which it was observed two distinct shocks were felt. The duration of the vibrations appeared to be unusually long, for at Indio and Warner Springs they were observed to continue through about 60 seconds of time. Mr. Wendell P. Hoge, of the Solar Observatory, Mount Wilson, wrote with reference to this shock:

> This earthquake was observed by Astronomer Dr. Harlow Shapley while observing with the 60-inch telescope. Star image oscillated rapidly back and forth in field of view in eyepiece. Two shocks close together were observed. Neither Dr. Shapley nor myself felt the shocks.

Mr. A. McConoll, agent for the Southern Pacific Company at Coachella, wrote in regard to the same earthquake:

> Had been threatening for some time. A very unsteady feeling could be felt for some minutes after, as if to start again. Sky to southeast very peculiar for nighttime. Noticed by all.

June 24th-30th. Los Angeles experienced marked but local seismic disturbances during the last seven days of June, when twelve distinct earthquakes occurred. However, most of them were light, no damage was done, and many residents of the city were unaware of their occurrence. Each disturbance consisted of but one vibration of brief duration. Three of the shocks which occurred within an interval of 15 minutes on the afternoon of June 26th were estimated to have an intensity of VI.

July 6th. What was probably the most severe earthquake of the year occurred in the Owens Valley at 3:01 a.m. on this date. This shock had an intensity estimated at VII. It caused a break 160 feet long in the concrete flume of the Los Angeles aqueduct at a point between the Haiwee reservoir and Owens Lake, in Inyo County. Under the direction of Mr. William Mulholland, Chief Engineer of the aqueduct, the damage was temporarily repaired by bridging the break with steel pipe. Since that time the flume has been rebuilt and reinforced. The water supply in Los Angeles was not cut off, because the break occurred above the Haiwee reservoir, which has a capacity sufficient for the storage of several weeks' supply of water for the city. In commenting upon this earthquake the San Francisco Chronicle published the following editorial on July 17th:

> This is important to the people of this city, for we are also preparing to bring water from the Sierra. It is known that there is an old fault between us and the Sierra and in the earlier plans for the Hetch-Hetchy enterprise two conduits were planned through the danger zone as insurance against interruption of supply.
>
> If it should appear that these breaks in the Los Angeles aqueduct, occurring on the same day, were due to seismic disturbance we should know it in order that in building our own works we may take the necessary precautions, which may be two conduits and extra strength through the danger zone.
>
> Since we have come to understand that an earthquake is nothing but the slipping of the earth for a few feet along some fault in the rocks, that phenomenon has lost most of its terror. The mischief that any earthquake of which there is human experience can do can be prevented by proper construction. The burning of San Francisco was due to improper construction of the main water

conduit supplying the city. We must take no more chances. If it appears that an earthquake damaged the Los Angeles tunnel, we must see to it that the danger is guarded against in our own enterprise.

July 7th-9th. The marked seismicity noted in the Owens Valley on July 6th seems to have migrated to the region of San Luis Obispo the following day, for nine earthquakes occurred in that vicinity in the three days, July 7th-9th, inclusive. These were disturbances of considerable energy, with intensities of VI to VII. The well recognized San Luis Obispo fault traverses this region and the movement was doubtless along this fault. Each of the nine earthquakes of this period consisted of but one shock, and none lasted more than ten seconds, and most for five seconds or less. The activity seemed to reach its climax on the afternoon of July 9th, when four distinct jars occurred at Arroyo Grande, in Lopez Canyon, ten miles southeast of San Luis Obispo. These shocks were violent and caused creaking of buildings and a decided swaying of hanging objects. Dishes were overturned, rocks rolled down the hillsides, and chimneys were cracked.

July 15th. On this date an earthquake of intensity IV was felt at 11:05 a.m. at Mount Wilson, Monrovia, and Sierra Madre. On Mount Wilson the houses creaked, at Monrovia a distinct twisting motion accompanied by a loud noise was perceptible, while at Sierra Madre a trembling motion was observed. In connection with this earthquake, Mr. Wendell P. Hoge, of the Solar Observatory, remarked:

> Weather partly cloudy, wind south, 3 miles per hour, humidity about 30%, temperature 87°. General character of the weather for several days such as is often spoken of as earthquake weather.

The term "earthquake weather" is often encountered in California, but meteorological text-books do not mention it. Those who use the term are unanimous in referring to a condition of hot and calm weather, without much cloud, but usually with more or less haze. The condition is not greatly unlike that which usually precedes a summer afternoon thunderstorm in the Middle West. As the term "earthquake weather" has not yet become commonplace in scientific literature it would be interesting to learn what seismologists think about the matter.

July 26th. An earthquake sufficiently vigorous to move furniture occurred at 12:31 a.m. on this date at Los Olivos, San Luis Obispo, and Santa Maria. At Los Olivos, where the intensity was estimated at IV, it consisted of but one shock of about 25 seconds' duration, which was accompanied by a roaring sound and trembling motion. At Santa Maria, where the intensity was estimated at V, it consisted of three vibrations, lasting about 15 seconds, and no sounds were heard. In reporting this earthquake, Mr. Roy E. Collom, of Santa Maria, added the following comment:

> Had impression of short foreknowledge of unusual event which might have been due to sounds. Writer retired at 10:30 p.m., was unable to sleep continuously because of feeling of depression and was awake at time of shock. This was the most vigorous shock I have felt since 1906. Talked to several people this morning (July 26th); all were awakened by the shock, and former San Franciscans have same impression, relative to vigor, as the writer.

September 12th and 24th. An earthquake which indicated movement along the San Andreas fault occurred at 3:26 a.m. on September 12th. It was felt at San Francisco and Berkeley on the north, southward throughout the Santa Clara Valley, and also at Santa Cruz, on Monterey Bay. It consisted of but one vibration of intensity II to III, and no sounds accompanied it except at San Francisco, where faint sounds were noted. A second earthquake of similar nature was felt throughout the same region at 1:21 p.m. on September 24th.

GENERAL CONSIDERATIONS

From a seismological standpoint the year 1917 was a normal year in California. While there were many minor shocks, few of high intensity occurred. No persons were injured either directly or indirectly as a result of the earthquakes. The total property damage for the year did not exceed $1,000 in value. The distribution of the earthquakes, their frequency, and intensity were all about as may be expected in an ordinary year in California. The high seismicity of the Imperial Valley is worthy of special attention, and indicates that another destructive shock may occur there at any time. The growing seismicity of Los Angeles and vicinity is also noteworthy, for 17 shocks occurred there, compared with but four during the preceding year. If the theory that a great earthquake is preceded for months and years by an increasing number of light shocks has any valid basis, the two regions mentioned will be worthy of special attention by seismologists in the immediate future.

Lassen Peak (lat. 40° 25′ N., long. 121° 45′ W.) which showed marked vulcanism in 1915, and occasional activity in 1916, continued to decline as an active volcano in 1917. No California earthquake which has occurred during the past three years can be related even remotely to this most recent cycle of activity.

Through coöperation with the seismographic station of the University of California in Berkeley the Weather Bureau has been interested to learn what proportion of sensible earthquakes reported to the Bureau has been recorded on the seismograph. It was found that nearly all of the earthquakes felt in northern California were automatically recorded by the seismograph at Berkeley, while but few of those which occurred in southern California were so recorded. None of the many light shocks which occurred in the Imperial Valley were sufficiently strong to affect the university instrument.

The earthquake hazard is well recognized by residents of California, and it is a factor which is considered by careful investors. Earthquake insurance is in growing demand. However, owing to the absence of trustworthy statistics in the past, rates have been more or less arbitrary, and most of them have no scientific basis. Moreover, through a gentlemen's agreement among California newspaper editors the subject of earthquakes is tabooed in the daily press. The general public promptly plunges into a kind of hysteria when a severe earthquake occurs, but soon relapses into complacent indifference to the subject when the immediate danger is over. A seismologist can therefore expect but little sympathy or support in the serious investigation of earthquakes. Furthermore, cities which have recently suffered damage from earthquakes seem to have benefited but slightly from their experience. San Francisco has learned its lesson in the matter of fire protection in a region of high seismicity. But projecting cornices and signs on buildings, overhead wires, and numerous other features indicate that much still remains to be learned and put into practice before earthquakes are rendered harmless. In the meantime the Weather Bureau will continue to gather and to publish earthquake statistics which it is hoped will eventually be of some use to the general public.

San Francisco, Cal.
January 21, 1918

EARTHQUAKES IN THEIR RELATION TO THE LOS ANGELES AQUEDUCT

SYNOPSIS OF REMARKS BY WM. MULHOLLAND[1] BEFORE A MEETING OF THE SOUTHERN SECTION AMERICAN INSTITUTE OF MINING ENGINEERS, LOS ANGELES, CALIFORNIA, JANUARY 7, 1918

There are scarcely any natural phenomena that appeal with greater force to the human mind than do earthquakes. This is quite natural for the reason that the human faith that looks to the solid ground and surrounding hills as being among the most permanent things in Nature, receives a severe shock when these things of accepted permanence shake and quiver. Until quite recent years, the real cause of earthquakes was a subject of discussion even among our learned geologists. The records indelibly written in the rocks themselves, however, have lately led to a very definite conclusion as to their cause. The speaker emphatically disclaims any real authoritative knowledge of earthquakes, further than that which has come to him by the experience common to nearly all here present, of having felt some of the more recent remarkable shocks which have occurred in this state, and the observations afforded him for study of the disturbed, fractured and dislocated condition of the rocks encountered in his every-day work as a civil engineer.

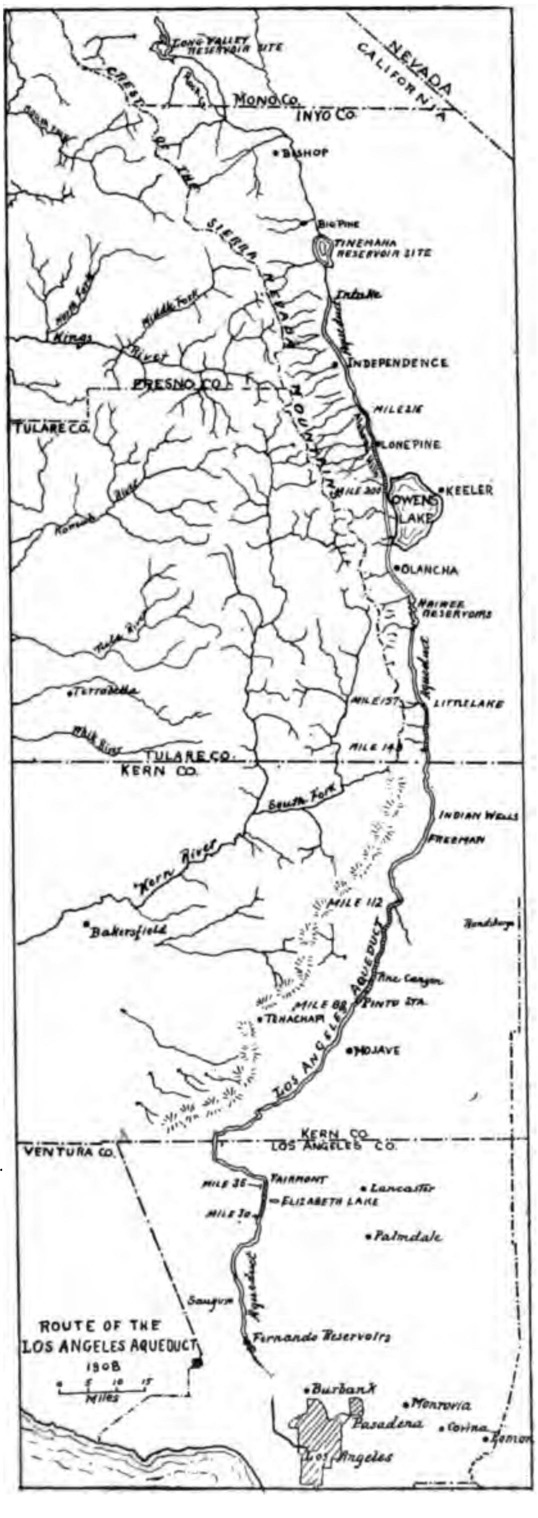
Even the ordinary layman, if of an observant turn of mind, cannot but be impressed, even though he has never felt an earthquake, with the fractured and disturbed condition of the strata of the more recent sedimentary rocks that obviously were laid down by the action of water, and necessarily in approximately horizontal beds. Observing as he must, the condition of broad areas of these rocks up-tilted, folded and fractured as disclosed by sectional views of them in canyons or artificial cuts, such as for railroads, road-ways, and so on, it would be a dull mind, indeed, which would not conclude that these contortions of the solid crust of the earth could not have been produced without disturbances that would be observable to the human senses, especially when the movements occurred in the hard and unyielding rocks, as well as in those of more pliant nature.

---

[1] Designer and builder of the Los Angeles aqueduct, Chief Engineer of the Los Angeles Bureau of Water Works and Supply.

The building of the Los Angeles aqueduct offered unusual opportunity for the observation of dislocations in the rock system of the country through which it passes, for the reason that in its 238 miles of length, fifty-three miles of which is in tunnels,—its course is crossed by and through the theater of geologically recent disturbance. It is to be regretted that, during the period of the aqueduct construction, the Engineering Corps lacked the services of a qualified geologist to note the geological manifestations disclosed by this great undertaking.

Just to mention a few of the interesting features, I will refer to the route of the aqueduct. It will be noticed that from Mile thirty to thirty-six, the aqueduct passes, by a tunnel, through the mountains forming the southerly rim of the Antelope Valley,—this range terminating at the west in the Coast Mountain mass, of which Mount Fraser is the dominant peak, and forming a continuation of the Sierra Madre Range, toward the southeast. This tunnel is called the Elizabeth Tunnel, by reason of the fact that it passes transversely across the valley in which lies Elizabeth Lake, at a depth of nearly four hundred feet below its floor. The Elizabeth Lake Valley, so called, is a portion of the depression of the San Andreas fault line, which is one of the major earth fractures on the Pacific Coast, west of the Sierra Nevada Mountains. At this point it runs approximately parallel to the ridge of the mountain range in which it exists, splitting it length-wise, with, roughly, about one-quarter of the mass lying to the north of the fault. Naturally, the curiosity of the aqueduct engineers was aroused, as to what would be revealed by the tunnel across the great fracture. At the northerly end of the tunnel, as it dives under the mountain, the formation is granite, somewhat decomposed and dissected by complex criss-cross fractures which rendered the ground quite blocky and made timbering necessary. However, before reaching the region of the fault, the rock became quite sound and compact. Crossing beneath the fault rift, the formation was found to be sheared with fair regularity into vertical leaves of variable thickness, with the fractures showing some slight degree of openness. The planes of fracture strike parallel with the direction of the Elizabeth Valley. This condition of fracture prevailed entirely across the valley, a distance of about three-quarters of a mile, and had all the appearance of a sunken block that in the stresses of movement had been sheared piano-key fashion for


ROUTE OF THE LOS ANGELES AQUEDUCT
1908
0 5 10 15
Miles
NEVADA
CALIFORNIA
Long Valley Reservoir Site
CREST OF THE SIERRA NEVADA MOUNTAINS
MONO CO.
INYO CO.
BISHOP
BIG PINE
TINEMAHA RESERVOIR SITE
Intake
Aqueduct
North Fork
Middle Fork
Kings River
INDEPENDENCE
FRESNO CO.
TULARE CO.
MILE 216
LONE PINE
MILE 200
OWENS LAKE
KEELER
Kaweah River
OLANCHA
HAIWEE RESERVOIRS
Tule River
Terrabella
White River
MILE 157
LITTLE LAKE
MILE 149
TULARE CO.
KERN CO.
South Fork
Kern River
INDIAN WELLS
FREEMAN
MILE 112
Randsburg
Bakersfield
LOS ANGELES AQUEDUCT
Pine Canyon
MILE 88
PINTO STA.
TEHACHAPI
MOJAVE
KERN CO.
LOS ANGELES CO.
VENTURA CO.
MILE 36
FAIRMONT
Lancaster
ELIZABETH LAKE
MILE 30
Palmdale
Saugus
Aqueduct
Fernando Reservoirs
Burbank
Monrovia
Pasadena
Covina
Lemon
Los Angeles

this whole distance. At the south of the fractured mass the mountain was found to be sound and compact.—the rock changing in character toward the south end of the tunnel. to a most beautifully knurled. banded gneiss. This rock was so tight in places as to be absolutely devoid of water and required in some instances the use of sprays to settle the dust after each round of shots was fired.

As the aqueduct passes from the mountains, which are the easterly extension of the Tehachapi Range, but which are known locally as the Pinto and Jawbone Mountains (Mile 89 to Mile 112), there is considerable evidence of quite recent faulting along the joint line between the alluvial formation of the valley and the mountain. In many cases there are jogs of as much as four to ten feet, appearing transversely in the high-pitched, cloudburst-formed debris cones of minor gorges issuing from the hills. This region is very arid, the rainfall not averaging more than three or four inches per annum. The most of this is in the form of violent cloud-bursts of very short duration, hence the fragmental discharges of the short canyons form cones of very steep pitch, the streams that create them always being. during their short existence, in an overloaded condition. It was the speaker's good fortune to witness two of these during the period of aqueduct construction. In both instances the discharge looked more as though some titanic concrete mixer had been discharged in the canyon than that the effect was one of purely rainfall precipitation. In one case, among many smaller stones, an angular block of granite of fully two cubic yards in volume appeared to be floating half submerged in the mass. The speaker cannot say from where this block was started, but it certainly came a mile or more and was finally deposited in the aqueduct. It is such fans as these that are quite numerous farther to the east than where this happened, which show transverse steps continuously across many of them for miles.

Passing from this region, the aqueduct emerges after a series of fourteen miles of tunnels on to the elevated west end of Salt Wells Valley, striking the mountains again back of Indian Wells, from which point it skirts the rim of the mountains, ascending higher and higher, until what is known as the Little Lake region is reached (Mile 150 to Mile 157). The Salt Wells Valley portion of the aqueduct consists of some cut and cover work on the flank of the mountains and some tunnels in good sound rock through the projecting spurs. The drainage lines are usually deeply eroded canyons crossed by inverted

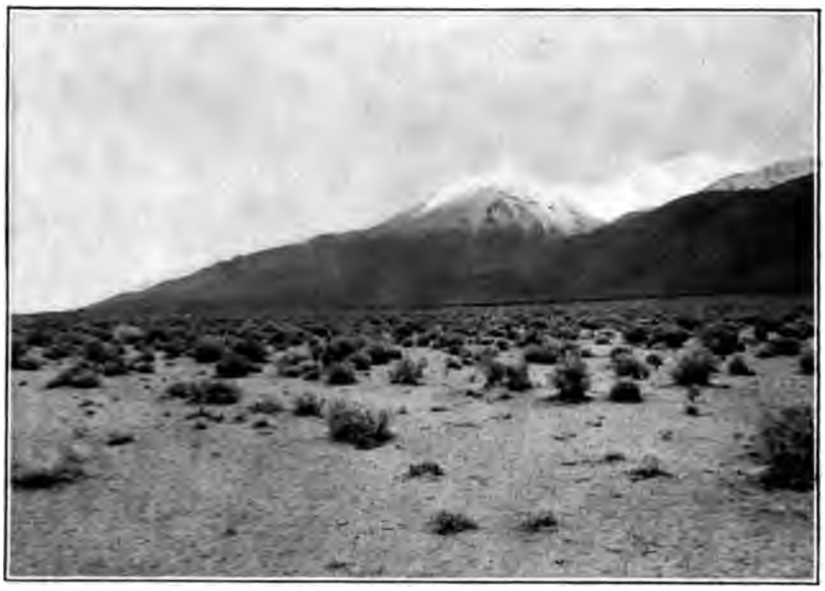


Figure 1. Scarp and detached slipping mass of mountain at Little Lake, looking south from Rose Valley.

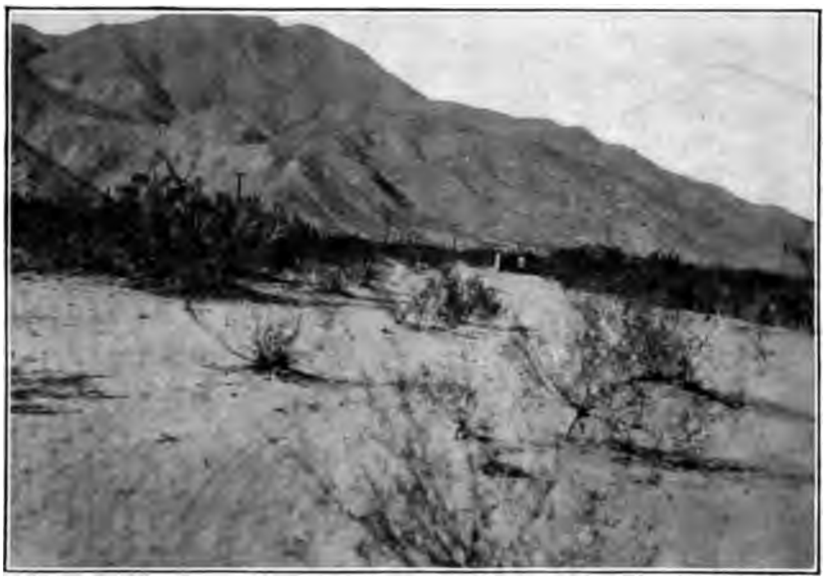


Figure 2. Same as Figure 1, looking north from upper end of Salt Wells Valley.

siphons. The mountain face of this region for a distance of sixteen miles displays a topography that indicates a mature and restful condition, the rough features of the mountain being quite effectively concealed by the sands of wind and weather erosion, giving generally soft outlines to the contours. This loose material, however, forms but a very thin cover, so thin in fact that all the cut and cover work of the aqueduct for the whole ditsance is founded in the rock.

Riding over the wagon road along the floor of the valley, as one approaches the Little Lake region, three features are conspicuously presented in the view looking north. By reference to the map it will be noticed that the Sierra Nevada, which here begins to assume form, takes a bend ten to fifteen degrees westerly. The ancient bed of the older Owens Valley drainage forms the thalweg of the valley and bears evidence of the violence of the torrents that passed through here into the ancient lake bed of the Salt Wells Valley and thence into the lake bed of the Searles Valley, from which the waters were dissipated southeasterly toward the Colorado River. The most striking thing about this old stream bed is its apparent freshness. Its appearance gives rise to the belief that it is occasionally flooded even at the present day. An examination of its bed farther north, however, dispels this delusion, as in its passage through the twelve miles of Rose Springs Valley from the Haiwee gorge to Little Lake, its sands and gravels are smoothly covered to a depth of from four to ten feet by sage and greasewood and aoelian drift.

Another conspicuous feature is the evidence of violent volcanic eruption on the immediate easterly banks of the ancient stream, the lavas being over 150 feet thick in places along the scarp of the stream bank and spreading radially from the group of volcanic cones lying to the east over an area of seventy or eighty square miles.

Viewing in perspective the Sierra Nevada Mountains on the west, there appears conspicuously a slide scarp originating near the very top of the ridge and a very marked step jutting easterly therefrom, which forms the skyline of a huge detached mass. The nose of this mass as it comes down to the old river bed, although much dissected by minor gulches, has the characteristic bluntness usually observable in rock slides. The displacement as shown on the scarp above, however, leads one to the conclusion that the displacement of this mass, which is five or six miles long by a mile or more wide, is only partly due to a slipping down with relation to the parent mountain, but rather to the mountain itself having been raised, leaving this as a detached member.

The aqueduct was carried through this mass from Mile 148 to Mile 156 in tunnels. The rock was nearly wholly granitic, occurring in thick alternating beds of dark coarse grained granite, hard and blocky, interspersed with masses of short grained pinkish granite with complex shearing planes presenting slippy faces. The impressive thing was the looseness of texture of the whole mass which in places showed a tendency to open fissures.

The aqueduct was pitched in elevation about 400 feet above the base of the mountain, and as before stated, was necessarily wholly in tunnels due to the rough, loose and entirely unreliable condition of the formation at the surface. In one of the gulches near the base of the mountain there was a small spring of so-called soda-water. The three tunnels in the immediate vicinity of this spring were driven with extreme difficulty owing to the presence of carbon dioxide gas issuing from the open texture of the rocks. A remarkable feature of this manifestation was that the amount of gas varied with the barometric pressure. When the barometer was high the gas gave little trouble, but with a drop of any considerable degree, even the two strong twelve-inch blowers employed for ventilation were found at such times to be inadequate to keep the air pure enough for the men to work.

This is the section of the aqueduct on which seismic disturbance is most frequent, the tremors not being at any time violent, but of such a nature as to give the impression that the main mountain above is still rising and that the oscillations are due to the lagging drag of this detached mass.

After passing this difficult region, nothing of seismological interest is encountered until the neighborhood of the Alabama Hills, above Owens Lake, is reached (Mile 200 to Mile 216). This was the scene of the great earthquake of 1872. The fault created by this shock, which had a vertical displacement in one place of about fifteen feet, passes closely along the aqueduct and loops across it at two points about three miles apart. Sufficient movement has taken place on this fault since the aqueduct was completed, without human observation of shock, probably being nothing more than slight superficial adjustments, to break the concrete in the aqueduct to such an extent that repairs were necessary. It was comforting to observe, however, that this particular fault is the only one noticeable in that portion of the valley that is of recent occurrence, and as the climate and rocky character of this ground are both favorable to the long preservation of the evidences of crustal disturbances, it is to be hoped that a period of comparative rest has been reached in this region. The scarp of 1872 looks as fresh as though it had occurred but yesterday, while evidences of movements antedating that one seem to indicate quite a remote period of time since their occurrence.

It must be borne in mind that this brief discussion is the result of the mere observation of a layman, and anything in the way of conclusions here made might be materially modified and differently construed by the studies of an experienced geologist.

EARTHQUAKES IN SOUTHERN CALIFORNIA[1]

By Homer Hamlin

During the past year I have been trying to collect data and records pertaining to earthquakes in southern California. At the outset I thought we might have eight or ten shocks, if it were a good year for earthquakes. In all, over fifty shocks have been recorded; but even these are not all, for I am sure that many slight shocks have passed unnoticed, or were not considered important enough to report. The effort is worth while and the work should be carried on even if it is rather strenuous at times, for we shall never solve our own earthquake problems until we study our own territory.

I will very briefly describe the location of some of the so-called earthquake regions in southern California, note some of the shocks which have occurred in past years, according to the scant records, and then those felt within the last year or so.

The San Andreas Fault.—That part of the so-called San Andreas fault which traverses southern California, extends southeasterly from the Tejon Pass along the southern border of the Mohave Desert, through the Cajon Pass, along the southern side of the San Bernardino Mountains, through the San Gorgonio Pass north of San Jacinto Mountain, and probably extends southeast along the desert mountains northeast of the Salton Sea to the Gila Mountains east of Yuma, Arizona, and on into the state of Sonora, Mexico.

Many earthquakes have originated along this fault, but only a few will be mentioned. In the vicinity of the Tejon Pass the San Andreas fault is intersected by the Tehachapi fault, which extends northeasterly at least eighty miles. Earthquakes seem to be unusually numerous and severe near this junction.

In 1852 an earthquake opened fissures in the ground for a distance of not less than thirty miles in the Tejon Pass region. Later in the same year, 1852, a violent shock was recorded at Yuma, Arizona. It threw down part of Chimney Rock, now known as Picacho Peak, and opened fissures in the clay desert bordering the Colorado River. Shocks were felt almost daily for many months. The mud springs, forty miles southwest of Yuma, now known as Volcano Lake, were also active, indicating that slipping also occurred on the adjacent San Jacinto fault.

---

[1] Read January 7, 1918, at the meeting of the American Institute of Mining Engineers at Los Angeles, California.

In 1857 a violent earthquake was felt from Yuma to Sacramento. The waters of Mokelumne River were thrown out upon the banks, leaving the bed dry in one place. The current of Kern River was turned up stream and the stream overflowed its banks. The waters of Tulare Lake were thrown upon its shores. Water in the Los Angeles River was thrown out of its bed. Houses were thrown down in San Fernando and San Diego. Fissures were opened in the ground in the San Gabriel Valley and in San Bernardino Valley. At and near Fort Tejon, in the vicinity of Tejon Pass, buildings were thrown down, large trees overthrown or broken down, and the earth was fissured for a distance of forty miles. Ridges several feet high were formed and the beds of streams changed.

In 1868 a severe earthquake fissured the earth near Dos Palmos, not far from Indio.

The earthquake of October 22, 1916, was the hardest and most widely observed shock of the year in California. It was felt from near Fresno to San Diego and from east of Mojave to the coast, over an area of 28,000 square miles, and was recorded instrumentally at the seismographic station of the University of California. Near the epicenter, in the vicinity of Tejon Pass, it was violent enough to break limbs from pine trees, roll rocks down the mountains, throw goods from store shelves, break dishes and cause very general alarm. The earth was very slightly fissured. The main shock was followed by seven after-shocks within a few hours, and by a decided shock a few days later.

During 1917 shocks have been reported from Palo Verde Valley, Needles, Yuma, Coachella, Victorville, and adjacent regions. All of these shocks probably originated on the San Andreas fault.

San Jacinto Fault.—The San Jacinto fault apparently branches off the San Andreas fault west of the Cajon Pass in the Lytle Creek region. It has a more southerly trend than the San Andreas fault, crosses the San Bernardino Valley between Colton and San Bernardino, passes along the west side of San Jacinto Valley, southwest of San Jacinto Mountain, crosses the mountains to the southeast, appears in the Imperial Valley, borders the northeast side of the Cocopa Mountains, and apparently extends into the Gulf of California.

About twenty-five miles to the southwest of the San Jacinto fault is another lineament known as the Elsinore fault. It extends from the Puente Hills toward the southeast, passing southwest of Elsinore, through the Warner Ranch country near Julian, along the west side of the Imperial Valley, *west* of the Cocopa Mountains in Mexico, and to the Gulf of California.

Many earthquakes have been reported from the region traversed by these parallel faults, but we have no data, among the older records, which show to a certainty which fault slipped. I am of the opinion that slipping occurred on both faults, and possibly on the San Andreas fault also, at or about the same time in some cases. The records do show, however, that severe earthquakes have occurred here; a fact further attested by the evidence furnished by fault traces and topographic forms.

A fault-slip on the San Jacinto lineament caused the Imperial Valley earthquake of April, 1915. The epicenter was in the vicinity of El Centro and Calexico. Many buildings were damaged and six persons were killed in Mexicala. The total property damage is estimated to have been $900,000.

Another earthquake occurred on the same fault at Volcano Lake in November of the same year. It was severe enough to fissure wet ground. After the shock the mud volcanos along the northeast side of Cerro Prieta, Black Butte, became very active and threw up a column of steam which reached the cloud line and resembled an immense snow bank balanced on a black pedestal.

During 1917 a total of fourteen earthquakes has been reported from the Imperial Valley region. The hardest shock was that of May 27th, which was felt over southern California from Los Angeles to San Diego, also an unknown distance in Mexico, and from the Colorado River to the coast. It was hardest in the Imperial Valley and at San Jacinto, suggesting that the slip occurred on the San Jacinto fault. No damage was done, although the shock was the most pronounced since those of 1915.

Other shocks have been reported from this zone, San Jacinto-Elsinore faults, or near it, from Elsinore, Rincon, Pomona, the region southeast of Hemet, and from Sierra Madre.

Coast Region.—In 1812 southern California was subjected to nearly continuous shocks for four and one-half months. Four days seldom elapsed without at least one shock. Many persons left their homes and lived out of doors.

In October of that year the mission at San Juan Capistrano was greatly damaged and at least thirty persons were killed. San Gabriel Mission was damaged and the top of the tower thrown down. In December of the same year the San Fernando Mission was damaged by a shock, also the Santa Barbara Mission. At Santa Barbara a suspended ball vibrated continually for eight days and at intervals for fifteen days.

In July, 1855, severe shocks were felt in Los Angeles and vicinity. The bells at the Mission San Gabriel were thrown down and two heavy waves rolled in at Point San Juan near San Juan Capistrano.

Our information regarding this series of shocks is so incomplete that it is impossible to say that the slips occurred on any one of many faults. Probably there was a general adjustment of strains over a large area. It should be noted, however, that fault phenomena are conspicuous near San Juan Capistrano and the shock which destroyed the mission could easily have been of local origin. In fact this seems very probable.

All of you know of the low swell or ridge southwest of Los Angeles which extends from the Palms to Dominguez Hill, Signal Hill, and to the southeast of Long Beach. The surface formations exposed are all Pleistocene and in places contain mammalian remains similar to those found in the La Brea beds west of the city. The ridge is of recent origin, geologically, and the forces which have elevated it are apparently still operating.

During 1917 no less than twenty earthquakes have been reported along this range of hills. In every case where the data have been worked up, the epicenter was found to be to the northeast of the hills in the low lands in the southwest part of the city. Evidently faulting or folding is in progress here, and more shocks may be expected. None of the shocks were hard, but those of February 13th and June 9th and 26th were strong enough to be noticed by many persons. No damage was done by any of them.

During 1917 other shocks have been recorded from the vicinity of Saugus and the Santa Clara River Valley.

Sierra Nevada Fault.—The major fault of the Sierra Nevadas is along the eastern front of the range. The escarpment along the western side of this fault zone is most conspicuous in the Owens Valley, where it rises very abruptly not less than 9000 feet above the valley. This lineament is not a single continuous fracture, but a series of parallel or nearly parallel faults, with some divergent branches and with conspicuous dropped blocks between some of the faults. Between Bishop and Owens Lake there are three main faults, the middle one following the valley in a general way.

Many earthquakes have occurred in the Owens Valley: the most notable one of which we have a record was in March, 1872. This shock was very violent and was felt over practically all of California and Nevada and at points in northern Mexico.

The slipping which caused this earthquake was on the middle fault, between Owens Lake and Bishop, and on other parallel faults south of the lake. Fissures were opened from Haiwee to a point north of Big Pine, a distance of seventy miles. In places the ground sank from two to thirty feet, ponds were formed and drainage lines were changed. There was a small tidal wave on Owens Lake. The east shore of the lake was slightly elevated and the west side depressed about two feet so that the road had to be rebuilt. Many adobe houses were destroyed and about thirty persons were killed and sixty injured.

During the past year seven earthquakes have been reported from this region. One in July, the hardest, was felt for about 100 miles along the fault zone.

EFFECTS OF AN EARTHQUAKE IN A MINE AT TOMBSTONE, ARIZONA

By W. F. STAUNTON, Mining Engineer

Evidence regarding the degree to which earthquake vibrations are perceptible below the surface of the ground and the physical effects of such vibrations seems to be very meager. This is doubtless due to the fact that people who have had such experiences seldom take the trouble to record them. The writer has been told by persons who have been in mines during earthquakes of quite marked surface intensity that nothing was felt underground; while others, in other mines, have reported that they were plainly felt. It is possible that both are right, and that the varying testimony is due to differences in rock structure, the neighboring rocks in one case transmitting the vibrations readily and in the other absorbing and deadening them, or possibly they are locally cut off by intervening cushions of inelastic material such as decomposed dikes. It is conceivable also that wave interference may locally cause stationary spots, or there may be nodes. Such phenomena are understood to be recognized by seismologists regarding the surface effects.

The writer has had the experience of being in a mine during an earthquake and it is to record a few observations regarding this experience that these notes are made.

In May, 1887, there was a succession of earthquake shocks, felt pretty generally throughout the southwest, but in more pronounced degree in southeastern Arizona, and to a still greater extent in northern Sonora, Mexico, where considable damage was done, and where it would have been very great if there had been many large structures in that locality. It was found later that the center of the disturbance was in Sonora, over 100 miles south of the international boundary line. A committee of investigation was sent down to report on the effects of the earthquake, and, as I remember, found a very extensive fracture, open in places, and with vertical displacements of many feet in the walls at intervals. Doubtless the report of the committee can be found in the papers of that time. An account was printed in the

Engineering and Mining Journal of June 11, 1887, covering surface effects in southern Arizona.

It appears to be well established that the vibrations were of sufficient intensity to constitute a fair working test of what earthquake vibrations might be expected to do to mine workings in their paths. At that time the mines of Bisbee and Tombstone were very extensively opened, and there were many miles of underground workings, including many large cavernous open stopes in the limestone, with little timbering. Notwithstanding these conditions, the actual damage underground was only trifling, while on the surface the shocks were sufficient to cause plaster to fall, to throw down chimneys, and disarrange foundations so as to require the resetting of engines.

Up to that time I had always understood that earthquake vibrations were not very perceptible far underground, but I found this to be a great mistake in some cases. In company with an assistant I was engaged on some survey work in a mine at Tombstone in a large inclined open stope about 150 feet below the surface. The first warning was a heavy roaring noise, followed almost immediately by the beginning of vibration which seemed to culminate in a very pronounced jolt. The first impression was that there had been an explosion of some kind, but I quickly recognized the vibrations for what they really were, as I had felt earthquakes before. The loosened rocks from the hanging-wall crashed down with much noise, striking sparks as they came in contact with the hard footwall, and for a few moments our situation was one of considerable danger and such as to leave a vivid mental impression.

At another mine where men were working at a depth of 500 feet, cutting out a chamber in hard limestone about a hundred feet from the shaft, they dropped their tools and rushed for the station, where they needed no urging to come up. They said they thought the mine was caving in, as everything seemed to be moving. One of the men told me that he was standing in a drift in hard white limestone; that he felt impelled to brace himself against the walls to maintain equilibrium, and that he distinctly saw a wave or deflection in the solid rock approach and pass him. He is not an imaginative person, and he has repeated this statement to me within the past few days, as he lives in Los Angeles, and I sought him to question him again about his experiences and sensations.

A man went to find a miner who was working alone in a very soft raise being put up from the 500-foot level, but strange to say, he had noticed nothing unusual and took the warning called up to him as a joke, refusing to come down. The vibrations so apparent in the hard rock seemed to have been absorbed by the softer, spongy rock.

So far as the writer's experience goes, it seems to show that, while earthquake vibrations extend at times to depths of several hundred feet in very pronounced degree, there is little to be feared in the way of material damage to mines from them even when of considerable intensity.

THE STUDY OF EARTHQUAKES IN SOUTHERN CALIFORNIA

By Harry O. Wood

The study of earthquakes has barely begun. There lies before us here a great, unexplored domain of nature.

No longer ago than the middle of the nineteenth century ideas concerning earthquakes ruled by the fancy of medieval, and even ancient, days still found respectable place in the world's opinion. However, at that time, Robert Mallet and Alexis Perrey had already set in motion a counter current of rational investigation. Encouraging progress has been made since then, especially during the last fifteen years. But even yet we are barely at the threshold.

We may declare with positive assurance that the expansion and refinement of knowledge about earthquakes will be of great usefulness to humanity, not merely through the development of science, and thence in secondary, ramifying ways, but to human welfare in very direct ways.

Seismology needs, asks for and deserves immediate, greatly increased support—for many and broad reasons.

But how are we to study earthquakes? They are not of hourly or daily occurrence. We cannot produce them at will. And if we could the public would scarcely take a kindly interest in such a method! Also, if they give us any warnings of their coming, as yet we do not understand these well. Therefore, in practice, we cannot experiment with earthquakes. This most powerful method of scientific inquiry is withheld from us. For no artificial disturbance, however great at and about its source, can compare in total energy, or depth of action, with a natural earthquake—even a weak one. Experimentation may assist us in minor ways, as in testing instruments, but the occurrence of earthquakes is too uncertain and too complex to allow much use of it in attacks upon the broader aspects of the problem.

Consequently we must depend upon the adequate, all-around study of natural shocks. Even more than in most branches of science, first-hand experience, observation and measurement of the phenomena of nature lie at the base of sound progress in seismology. We must study earthquakes where and when they occur,—and, when and *where* they occur we must study them.

Now where *may* we study natural earthquakes? Any community, or any land, may be visited by an earthquake. This is the possibility. But it is not the rule. Almost everywhere the occurrence of an earthquake strong enough to be generally noticeable is the event of a generation, if not of a lifetime or longer, while strong shocks practically never occur. To be sure, in all places, with sensitive seismographic devices we may study the waves of strong earthquakes proceeding from distant lands. Very important knowledge has thus been gained. But the most pressing earthquake problems cannot be attacked and solved in such ways,—those especially which bear most directly upon human welfare. In most places, therefore, only a partial study of earthquakes can be conducted.

On the other hand, we know regions where earthquakes are common,—where weak shocks are frequent, while strong shocks and destructive shocks occur at longer intervals. In all these regions, since the occurrence of shocks in each exhibits peculiarities of its own, the study of seismology is of paramount importance. For it is only in such places that our knowledge of earthquakes can be extended adequately and progress be accelerated at a reasonable pace. Moreover, in these places there is a threat of danger to life and to property,—a condition which demands our best knowledge of the time and place of impending disaster, of how shocks may act to produce destruction, and how their effects may be prevented or minimized,—since their causes and occurrence are beyond human control. In all these regions the study of earthquakes not only affords great opportunities for the advancement of science, which do not exist elsewhere—of which, therefore, we must take full advantage—but it constitutes a public duty on humanitarian grounds as well.

California, and the territory which adjoins it, is such a region. Here both duty and opportunity call. Many problems, and methods of attacking them, are clearly seen. There only is needed an adequate financial basis for undertaking work.

About a year ago there were published two studies dealing with the problems presented in this province. One was an effort to synthesize the crude and imperfect records of past years, and so to indicate the lessons these teach and the problems they pose, and to point out the directions of inquiry thus suggested. The other stated at some length a plan for the adequate and systematic study of these problems, so far as we can comprehend and visualize them in the present state of knowledge.

This plan, as a whole, was comprehensive. To undertake and carry on the work outlined by it in its more complete form would require considerable income,—hence its proper, enduring support would call for a fairly large endowment. Eventually such support must become available.

But it was not, and is not, deemed wise to undertake the whole program, or even a large part of it, at the beginning. For in early stages of the work abnormally rapid progress is anticipated. At short intervals marked improvements in instrumental equipment should be devised and introduced, necessitating the discarding and replacement of mechanisms already in use New findings may bring about readjustments of emphasis upon the relative values of different lines of inquiry. New problems must arise, calling for new methods of attack. As a consequence of such advances in knowledge and methods, details of the plan almost surely may be modified with advantage.

So, from the first, for many reasons, growth from a small beginning has seemed the desirable way to put the plan into effect. But here words of warning seem necessary. First, the beginning should be upon a basis adequate to insure progressive work from the outset, otherwise the early results will be sparse and often ambiguous and thus their direct usefulness will be impaired and, worse yet, the promising character of such work will be obscured. In other words, we ought not to begin too modestly. And second, the greater needs of the expanding or complete program should be visualized clearly, and so the earliest foundation should either provide for the future development directly, or, failing that, it should leave the field clear, both in matters of law and in matters of sentiment, for development in future without friction or hindrance.

With all this in mind, a plan for beginning on a much smaller scale was set forth in the study mentioned; and in this it was urged strongly that the work therein indicated should be begun at an early date in southern California.

Why should this beginning be made in southern California? Because, this is a region of much economic importance, and, for the west, a densely populated area where weak earthquakes occur at no great intervals and where strong and destructive shocks have occurred. Between 1769 and 1857 several very powerful shocks originated here. After 1857 an interval of comparative quiet followed, until 1915 when strong shocks again occurred in the Imperial Valley. We cannot yet make earthquake predictions with confidence, but on the basis of this history, it is the part of wisdom and foresight to expect here the occurrence of strong shocks and a greater frequency of weak shocks in the years of the immediate future. For there is no reason for thinking that the fundamental causes which produce them have declined in action or ceased to operate here. Here, too, is a good place for our undertaking because we have a relatively small region, naturally isolated by sea, desert, and mountain walls, in which our study can be begun and its importance demonstrated, and emphasized, by the establishment and equipment of relatively few seismometric stations, and the conduct of field investigations on a relatively small scale. Here, therefore, relatively small initial income would be required.

The details of this preliminary, subordinate plan, and the discussion of necessary and desirable station equipment, may be found in the published study referred to. There is no need to reiterate this here. But a short general outline may be of immediate interest.

As a first step one station should be established, preferably in the Los Angeles-Pasadena district. (Ultimately the chief station of the system—a station of the first class—should be located here.) At first it is desirable that this station should be equipped with several types of seismometers, including all likely to be serviceable in recording local shocks; and, most important of all, if possible, provision should be made for experimentation and the constructing and testing of more promising types. Only through the use of better types of seismometers than any now known can progress be accelerated at a desirable rate in the study of local shocks. Many types of seismometers now in general use could be dispensed with altogether because:

(*a*) they are ill-adapted for registering local shocks, and

(*b*) better types than they are known already for the mensuration of waves from distant sources.

Also, from the beginning, means should be available for expeditions and investigations in the field within the area.

Additional stations should be established as soon as means can be found to support them, especially after a type of seismometer suitable for registering local shocks is found or developed. When it is feasible at least two suitably placed and suitably equipped stations should be added. Little clean-cut, definitive progress can be expected until at least three adequate stations suitably located and spaced have been operating for a time—a length of time which will depend a good deal upon the frequency of earthquakes within the region of sensibility of all three stations. Until we have data of this degree of definiteness and refinement to digest and synthesize, the work will remain in the intuitive and problem-suggesting stage. Definite conclusions must be based upon definite information.

Three adequately equipped stations will serve to locate the positions and depths of origin of all shocks well registered at all three places. All places of origin thus definitely marked must then be related to knowledge of geological structure and peculiarities derived from careful studies in the field.

The desirability of extending the network of stations, at least until all that are needed for the southern California province are in operation, should be obvious without further comment.

The aims of the geological work conducted in the field would be several, among them:—

(*a*) to locate systems of faulting upon which shocks do or may originate,

(*b*) to determine the mechanisms and surface and structural characteristics of the movements of fault-slipping along these systems,

(*c*) to correlate seismometric indications with geologic indications,

(*d*) to determine the facts, and then the mechanisms and causes, regarding areal variation in shock effects.

Now at the present time, owing to the world-war, it will be difficult, very likely impossible, to procure seismometers from the usual sources. Certainly no adequate equipment can be bought at the moment. But this need not necessarily postpone the work. For it should be possible, if means are found, to construct and test experimental types—a very important duty of the undertaking—while it is possible that some seismometer might be found with which to begin registration. If such preliminary registration served no other purpose it would afford an idea as to the usual strength and the usual frequency of the occurrence of registrable shocks within a radius of 50 to 100 kilometers of the station.

But not much important progress can be expected to result until seismometric registration with adequate apparatus has been carried on for a time at three stations at least.

A beginning upon the work in the field can be made now as well as later. In fact, a considerable amount of field investigation may advantageously precede work at the seismometric stations,—unless these were to be better equipped than now is possible.

In conclusion it need only be said that the value this work will come to have can scarcely be overestimated. It cannot be done without financial support, for the employment of men and the purchase, construction, and installation of equipment. And the exact needs and exact course of action cannot be completely foreseen.

NOTE ON THE VELOCITY OF LONG WAVES AND THE AVERAGE DEPTH OF THE OCEAN

By Harry Fielding Reid

The theory of water waves shows that waves, whose wave-length (that is, the distance between successive crests) is many times as great as the depth of the water, advance with a velocity which depends only on the depth of the water and is independent of the wave length. The relation is

$$v = \sqrt{gh} \qquad (1)$$

where v is the velocity of propagation of the waves, g the acceleration of gravity, and h the depth of the water. This expression can be used for two purposes; we can determine the velocity of propagation if we know the depth, or we can determine the depth if we measure the velocity.

A. D. Bache, Superintendent of the U. S. Coast and Geodetic Survey, first conceived the idea of finding the *average* depth of the Pacific Ocean by applying this formula, the velocity of propagation being determined by the time taken by sea waves, set up by earthquakes on the Japanese coast, December 23, 1854, to travel to the tidal stations at San Diego and San Francisco.[1]

But the application of the formula for determining the *average* depth from the *average* velocity is not justified, as the velocity is not proportional to the depth, but to its square root. It developed later that the average depth determined from this formula was always too small; and this gave rise to various explanations, until Charles Davison pointed out[2] that the formula would necessarily give too small a depth, because the average of the square roots of the various depths passed over was smaller than the square root of the average depth.

---

[1] "Notice of Earthquake Waves on the Western Coast of the United States on the 23d and 25th of December, 1854." By A. D. Bache, Superintendent United States Coast Survey, in the *American Journal of Science*, 21, 37-43, 1856; and in Report United States Coast Survey, 1855, Appendix 51, pp. 342-346; and again, with slight additions, in 1862, Appendix 24, 238-241. A copy of the tidal records is reproduced with these articles.

[2] "Note on an Error in the Method of Determining the Mean Depth of the Ocean from the Velocity of Seismic Sea-waves." *Philosophical Magazine*, **48**, 33-36, 1897.

Davison's proof will not be evident to persons not very familiar with mathematical analysis; but his results can be obtained by a very simple procedure. From equation (1) it follows that

$$dt = \frac{ds}{v} = \frac{ds}{\sqrt{gh}} \tag{2}$$

where dt is the time for a wave to pass over the element ds of its course. The time necessary to pass over two elements of the same length, but of different depths, will be

$$dt_1 + dt_2 = \frac{ds}{\sqrt{gh_1}} + \frac{ds}{\sqrt{gh_2}} = ds\left(\frac{1}{\sqrt{gh_1}} + \frac{1}{\sqrt{gh_2}}\right) \tag{3}$$

Let h be the average depth of the two elements and write $h_1 = h + k$ $h_2 = h - k$; then

$$\frac{1}{V} = \frac{dt_1 + dt_2}{2ds} = \frac{1}{2\sqrt{gh}}\left(\frac{1}{\sqrt{1 + k/h}} + \frac{1}{\sqrt{1 - k/h}}\right) \tag{4}$$

where V is the average velocity, corresponding to the total distance passed over divided by the total time taken. This equation gives for the correct average depth of the two elements

$$\mathrm{h} = \frac{V^2}{g} \times \frac{1}{4}\left(\frac{1}{\sqrt{1 + k/h}} + \frac{1}{\sqrt{1 - k/h}}\right)^2 \tag{5}$$

whereas Bache, by substituting the average velocity and the average depth in formula (1) got

$$\acute{h} = \frac{V^2}{g} \tag{6}$$

In formula (5), k/h varies from zero, when the two depths are equal, to unity when the smaller depth becomes zero. The following table, which gives the value of the factor $\frac{1}{4}(\quad)^2$ for various values of k/h, shows that it is always greater than unity, and therefore the true average value of the depth is always greater than the value obtained from Bache's formula.

k/h	$\frac{1}{4}(\quad)^2$
0.1	1.01
0.2	1.03
0.4	1.14
0.7	1.68
1.0	∞

We see that the difference between the two formulae increases as k/h increases: i. e., we may have considerable variations in the depth, if the latter is large, without materially affecting the average velocity; but for shallow depths small variations are important.

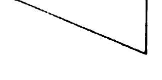
We may divide the path of the wave into pairs of elements and determine the average depth of each pair; if we use Bache's formula, we shall obtain too small an average depth for each pair; therefore, when we combine these pairs to determine the average depth of the whole course, the result will be too small.

To determine the time taken a wave to travel over a course of varying depth, we must integrate equation (2), and this evidently can only be done when we know the relation between h and s: i. e., when we know the distribution of depth. Therefore, the determination of the mean depth by means of the average velocity of a long wave, requires us first to know the depths at all parts of the wave's course; and with this knowledge the mean depth can be determined directly more easily than by means of the mean velocity of the long wave.

Let us see how large an error we make by applying Bache's formula to a uniformly sloping bottom. Let h_1 and h_2 be the depths at a distance apart S; let $\tan\alpha = p$, then from figure, $h = h_1 + ps$, and equation (2) becomes

$$\int dt = \int_0^S \frac{ds}{\sqrt{g(h_1 + ps)}}$$

$$\therefore \ T = \frac{2S}{\sqrt{g}} \, \frac{\sqrt{h_2} - \sqrt{h_1}}{h_2 - h_1} = \frac{S}{\sqrt{g}} \left(\frac{2}{\sqrt{h_1} + \sqrt{h_2}} \right)$$



If h_1 and h_2 differ but slightly in comparison with their average, Bache's formula could be used with small error. As a particular case, suppose h_1 equal to o; we then have the case of a wave passing from or to a shore line. The true average depth would be $h_2/2$; and from equation (7)

$$h = \frac{h_2}{2} = \frac{2V^2}{g} \tag{8}$$

which is just twice the depth that would be obtained by using Bache's equation.

We cannot use Bache's equation to determine the mean depth of the ocean; but if we know the distribution of depth, we can determine the time taken by a wave to travel between two points. This method was very useful in studying the movement of the water along the English Coast caused by the great Lisbon earthquake[3] and made it possible to show that in many places the water was disturbed by the earth vibrations there, and not, as had been supposed, by the sea-waves, which could only have arrived many hours later. In calculating the time taken for a wave to travel over a stretch where the variations of depth are small compared with the depth itself, we may substitute the average depth without much error. In approaching shallow water we should use equation (7).

By comparing the time of arrival of an earthquake shock with the time of arrival of the sea-wave, the origins of some off-shore earthquakes have been estimated. This estimation could be greatly improved by considering carefully the distribution of depth in calculating the time necessary for a sea-wave to travel to the shore from various distances.

Johns Hopkins University,
Baltimore, March 2, 1918.

---

[3] "The Lisbon Earthquake of November 1, 1755." *Bulletin Seismological Society of America*, **4**, 55-80, 1914.

SEISMOLOGICAL NOTES

Los Angeles, California, November 23, 1917.—There was a shock at 7 p.m. lasting about one second. It was reported by two persons at rest and caused distinct rattling of doors, windows, etc. This shock was in the area in which so many were felt during the year 1917.—Homer Hamlin.

Calexico, California, December 20, 1917.—At 12:23 a.m. a slight shock was felt at Calexico. It lasted from four to five seconds and was noticed by several persons at rest. It caused jarring of buildings, creaking of walls, ceilings, and swaying of suspended articles. It was accompanied by a faint rumbling sound.—Reported by C. N. Perry to Homer Hamlin.

Guatemala, December 25, 1917, to January 26, 1918.—The last number of this BULLETIN briefly mentioned (vol. VII, p. 142) the disastrous earthquakes that destroyed a large part of the city of Guatemala. The shocks began December 25th and continued until December 31st. On January 5th press dispatches reported that the shocks had continued up to that date with varying frequency and intensity. About a hundred deaths had been reported, most of the houses were uninhabitable, and practically the entire population was in the streets. The cathedral, the palace and the postoffice had all fallen, Las Vacas bridge to Barrios was down, and railway traffic between Guatemala and San José had been interrupted by landslides on the line. Some of the adjoining towns had also been badly damaged. The walls of the insane asylum and of the jails were thrown down on the second day, and the patients and prisoners escaped. The cemetery walls in which dead bodies were buried having been thrown down, the coffins and dead were exposed to view. Fortunately no fires broke out among the ruins of the city. It is said that the neighboring volcano of San Salvador recently ceased its customary eruptions, and that the earthquakes immediately followed.

The latest dispatches received in this country on January 26th, report continued shocks and say that the people are leaving the city of Guatemala; the firm of W. R. Grace & Co. has moved its offices to Esquintla. The suburban railways are still in poor condition. Two thousand refugees are being cared for at the Red Cross camp, and though they have no other shelter, there is no lack of food supplies.

February 25, 1918.—Press dispatches from San Salvador on February 25th state that communications with the interior of Guatemala have been interrupted by violent earthquakes. The exact locality is not mentioned.

Guyaquil, Equador, January 10, 1918.—The volcano of Tunguragua in central Equador erupted for several days prior to January 10th. It is reported that the town of Baños at the foot of the volcanic peak has been destroyed.

Swatow, China, February 16, 1918.—A violent earthquake occurred at Swatow, China, on February 16th. It seems to have reached a high intensity over a large area that is not clearly defined, but includes Chong Chow. More than a hundred buildings were damaged or quite destroyed, and two hundred persons were killed.

Kilauea, February 28, 1918.—The floor of Kilauea crater was rising on February 28th, and an overflow of lava was expected.

Yakima, Washington, February 28, 1918.—An earthquake was felt throughout the Yakima Valley in Washington at 3:45 p.m., on February 28, 1918. Houses swayed, windows, doors and dishes rattled, but no damage was done.

Los Angeles, March 6, 1918.—A slight shock was felt at 10:25 a.m. on March 6th, through a zone extending across the city of Los Angeles. No damage was done.

Venice, California, March 6, 1918.—A shock was felt by many persons at Venice, California, at 10:21 a.m. on March 6, 1918. There was a rocking movement that lasted from five to seven seconds, and was accompanied by an explosive rumbling sound. There was some alarm, but no damage was done except the breaking of a few dishes. The intensity is estimated to have been about V of the R.-F. scale.—Dr. James T. Brown.

Venice, California, March 8, 1918.—An earthquake was felt by many persons at Venice, California, at 4:27 a.m. on March 8th. It lasted about two seconds, and was accompanied by a rumbling sound. The intensity is estimated at nearly V of the R.-F. scale.—Dr. James T. Brown.

Spokane, Washington, March 11, 1918.—At Gonzaga University, Spokane, Washington, an earthquake was recorded at 8:26 p.m. on March 11th by the university seismograph. It had an intensity of IV of the R.-F. scale, and lasted about two seconds. It was distinctly felt also at several stations along the Northern Pacific Railway, where walls swayed and doors and windows rattled. It was felt also at Trout Creek and Heron, Montana, and at Cabinet, Clarks Fork, Sant Point, and Rathdrum, Idaho.—A. M. Jung, Seis. Observer.

Sierra County, California, March 12, 1918.—Two sharp earthquake shocks were felt at 2:30 a.m. and at 4:30 a.m. on March 12, 1918, over a large area in Sierra County, California. A few chimneys were thrown down, but no serious damage was done.

REVIEWS

The Bulletin Semestriel de l'Observatoire Météorologique du Séminaire-Collège St. Martial at Port-au-Prince, Haiti, for the months of July to December, 1916, contains the reports of earthquakes registered at the Port-au-Prince seismologic station from September 23, 1916, to August 31, 1917. Out of some thirty-odd shocks recorded, only one, on July 26, 1917, reached an intensity of VI of the R.-F. scale. This shock was felt over most of the island of Haiti. It occurred at 8:11 p.m., and reached an intensity of V or more at several places. At Puerto Plata it lasted seventy-five seconds, reached an intensity of VI, and caused general alarm. At Limonade it lasted fifteen seconds and had an intensity between V and VI. At Cape Haitien the intensity was VI; at Bayeux V; at Port-de-Paix, IV.

Organization and publications of "El Servicio Seismológico Mexicano." Summary of an editorial in the "Boletin Mensual del Observatorio Meteorológico y Seismológico Central de Mexico," No. 8, August, 1916.

The monthly bulletin of the Central Meteorological Observatory of Mexico is primarily a catalogue of the observations of the various seismological and meteorological observatories and stations in Mexico. The bulletin dated August, 1916, contains a brief history of the development of the seismological service of the Republic of Mexico.

In June, 1903, Sn. Ing. Jose G. Aguilera took part in the second conference of the International Seismological Association in order to study the seismic problems, the solution of which requires the coöperation of numerous stations distributed over the world. In 1904 a provisional station was attached to the National Astronomical Observatory and equipped with two Bosch-Omori pendulums of 10 kilos, and further equipment was obtained in 1905.

In 1908 the Servicio Seismológico Nacional was established as a department of the Instituto Geológico. This department was to consist of one central seismological station of the first order and fifty-two of the second order. The equipment of the central station was to include a Wiechert horizontal seismograph of 1200 kgs., a Wiechert vertical seismograph of 1300 kgs., and barographic, hydrographic, and thermographic instruments. The equipment of the stations of the second order was to be a Wiechert horizontal seismograph of 200 kgs., and a Wiechert vertical seismograph of 80 kgs. and meteorological self-registering instruments.

Due to unsettled conditions in the Republic, the carrying out of the original plan has been delayed and only three stations are in operation. These are the central station, the station at Mazatlan and the station at Oaxaca. The central station was closed February 3, March 23, and August 1 to August 10, 1915, and was then established as a department of the Observatorio Meteorológico Central.

The following is a list of publications of the department:

La zona magaséismica Acambay-Tixmadeje, por F. Urbina y H. Camacho. Boletin 32, Instituto Geológico Nacional.

Parergones del Instituto Geológico Nacional: T. I; T. II, No. 10; T. III, Nos. 3, 8, y 10; T. IV, No. 1; T. V, Nos. 1-3 y 6-8. These contain the catalogue of the earthquakes that have occurred in Mexico between 1904-1912 inclusive.

The Geological Institute will publish the catalogue up to July, 1915, and from this date on, the lists of earthquakes will appear in the monthly bulletin of the Central Meteorological Observatory.

C. F. TOLMAN, JR.

SEISMOLOGICAL REPORTS RECEIVED

AMERICA

Denver, Colorado.—Jesuit Seismological Service, Sacred Heart College. Reports nos. 11 and 12, November 1 to December 31, 1917, and nos. 1 and 2, January 1 to February 28, 1918.

La Paz, Bolivia.—Boletin Sismico del Observatorio del Colegio San Calixto (P. P. Jesuitas). Reports nos. 5 to 14, from February 4 to October 5, 1917.

Ottawa, Canada.—Earthquake Station, Dominion Astronomical Observatory. Reports nos. 22 to 25, November 1 to December 31, 1917, and nos. 1 to 3, January 1 to February 28, 1918.

Washington, D. C.—Seismological Bulletin of the Georgetown University, nos. 32 to 34, from November 1, 1917, to January 31, 1918, and compiled press dispatches from November 16, 1917, to January 27, 1918.

ASIA

Zi-Ka-Wei, China.—Bulletin Sismique de l'Observatoire, nos. 13 to 16, August 15 to December 31, 1917, and no. 1, January 3 to 30, 1918.

EUROPE

Coimbra, Portugal.—Boletin Sismico do Observatorio da Universidade, nos. 7 to 9b, October 1 to December 31, 1917, and no. 1, January 1 to 31, 1918.

PHILIPPINE ISLANDS

Manila, P. I.—Seismological Bulletin of the Observatory, nos. 25 to 30, August 1 to September 30, 1917.

PUBLICATIONS RECEIVED

Boletin Mensual del Observatorio Meteorologico y Seismologico Central de Mexico, nos. 1-12, Enero-Deciembre de 1916.

Bulletin Semestriel de l'Observatoire Météorologique du Séminaire-Collège St. Martial, Port-au-Prince, Haiti. Janvier-Decembre, 1916.

Boletin Mensual; Oficina Meteorologica Nacional; Republica Argentina. Año 1, nos. 6-12. Buenos Aires, 1917. Año 2, no. 1, 1917.

Anales de la Academia de Ciencias Exactas Fisicas y Naturales: Nueva contribucíon a la determinacion racional de algunas funciones sismicas, de Galdino Negri. La Plata, 1917. 230 pp.

ROSSI-FOREL SCALE OF EARTHQUAKE INTENSITIES

I. **Microseismic shock**: recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds; the shock felt by an experienced observer.

II. **Extremely feeble shock**: recorded by several seismographs of different kinds; felt by a small number of persons at rest.

III. **Very feeble shock**: felt by several persons at rest; strong enough for the direction or duration to be appreciable.

IV. **Feeble shock**: felt by persons in motion; disturbances of movable objects, doors, windows; creaking of ceilings.

V. **Shock of moderate intensity**: felt generally by everyone; disturbance of furniture, beds, etc., ringing of swinging bells.

VI. **Fairly strong shock**: general awakening of those asleep; general ringing of house bells; oscillation of chandeliers; stopping of pendulum clocks; visible agitation of trees and shrubs; some startled persons leave their dwellings.

VII. **Strong shock**: overthrow of movable objects; fall of plaster; ringing of church bells; general panic, without damage to buildings.

VIII. **Very strong shock**: fall of chimneys, cracks in walls of buildings.

IX. **Extremely strong shock**: partial or total destruction of some buildings.

X. **Shock of extreme intensity**: great disaster, buildings ruined, disturbance of the strata, fissures in the ground, rock-falls from mountains.

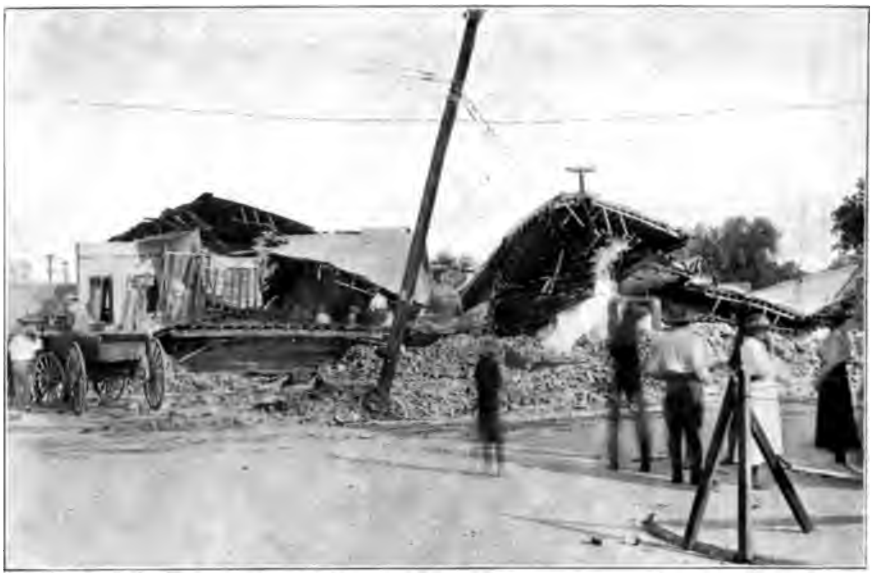


Fig. 1. Corner view of main business block of San Jacinto. Negative taken April 24, 1918, by S. D. T.

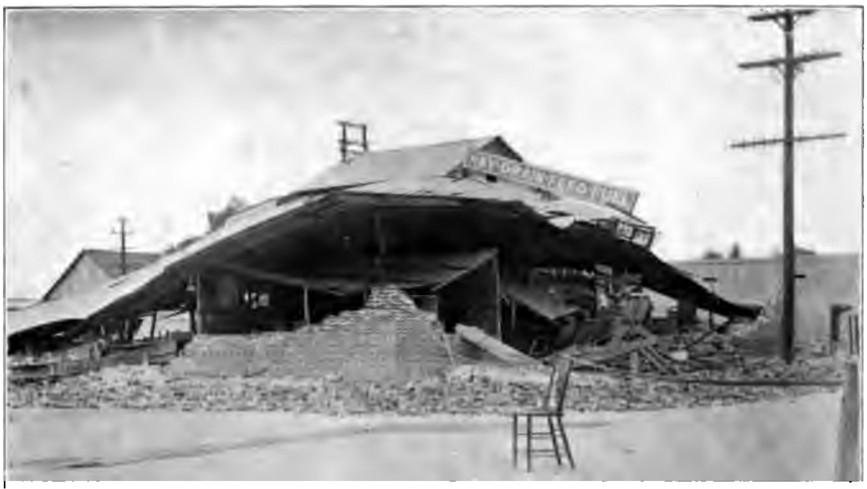


Fig. 2. In same block as Fig. 1 at diagonally opposite corner. On right is wall of concrete building which was not seriously damaged. Negative taken April 25, 1918, by S. D. T.

The Bulletin of the
Seismological Society of America

VOL. VIII JUNE-SEPTEMBER, 1918 Nos. 2-3

THE SAN JACINTO EARTHQUAKE OF APRIL 21, 1918

By Sidney D. Townley

From data collected by Homer Hamlin, A. M. Strong, Frank Rolfe, and the author

Introduction

On April 21, 1918, the whole of southern California and western Arizona was shaken by an earthquake of marked intensity. The shock came, without sensible foreshocks, at 3:32 p. m. (Pacific Coast Daylight-Saving Time) or 22:32 Greenwich Mean Civil Time. Newspaper reports published on the morning of April 22d indicated that the greatest damage occurred in the small city of San Jacinto, Riverside County, California. San Jacinto is in latitude 33° 47′ north and longitude 116° 58′ west, approximately thirty miles southeast of Riverside and seventy-five miles east by south of Los Angeles. Some of the buildings in Hemet, two miles south of San Jacinto, were also badly damaged. The population of each of these places is approximately 1,000.

Investigations

In accordance with the policy which the Seismological Society of America has adopted of making field investigations of all severe earthquakes occurring within a reasonable distance from San Francisco, the official headquarters of the society, the author of this article, in company with Mr. Homer Hamlin, of Los Angeles, spent three days, April 24th to 27th, in San Jacinto and vicinity, investigating the effects of the earthquake and the geologic formations of the region.

Later, Mr. A. M. Strong and Mr. Frank Rolfe, of Los Angeles, spent from May 5th to 13th making further investigations in the mountainous region to the southeast of San Jacinto Valley. The results of their investigations are published as a separate article in this number of the Bulletin.

Dr. Ralph Arnold, of Los Angeles, to whom acknowledgment is due for assuming a considerable portion of the expense of these investigations, has made a study of the fault system of the San Jacinto region, and the results of his work are also published as a separate article in this number of the Bulletin.

For a number of years Mr. Homer Hamlin, at his own expense, has been collecting data concerning earthquakes from all portions of the southern part of California. He has prepared report sheets containing a large number of questions, which are distributed to his correspondents and returned to him properly filled out whenever an earthquake is felt. These reports, and a few others obtained by Messrs. Strong and Rolfe, constitute the data from which the isoseismal curves have been drawn for the map accompanying this article. (Plate 5.)

The reports collected by the U. S. Weather Bureau from its observers in California and Arizona and published in the *Monthly Weather Review* for April, 1918, have also been consulted and used as a check upon the conclusions reached from the data collected by Mr. Hamlin.

Topography and Fault System

The topography and the system of faults in the region around San Jacinto are described in Dr. Arnold's article, pages 68-73 of this number of the Bulletin. The fault system, as worked out by various persons, is given in Plate 13, opposite page 68. Dr. Arnold has drawn the main fault line directly through the city of San Jacinto, and there is considerable evidence to support this location. It is not my purpose to take up a full discussion of the evidence of the location of this fault, but to mention only some of the evidence found by Mr. Hamlin and myself in our visit to the ranch of F. A. Blackburn. This ranch is located in the Bautista Creek Canyon, about eight miles southeast of San Jacinto (San Jacinto quadrangle, sections 26 and 35, 5 S., 1 E.). On the day following the earthquake two boys living in Hemet went into the hills east of the Blackburn ranch and reported the finding of a place where a piece of ground about ten acres in extent had sunk several feet. Mr. Hamlin and I attempted to find this sink, but did not succeed. We did, however, find three old sinks which we considered clear evidence of a fault line. Fresh earth cracks were found around the sides of these sinks and it was probably these which led the boys to think that the whole area of the sink had gone down on April 21st. We saw three of these sinks, but were told at the Blackburn ranch that there were seven. If a line be drawn through Hog Lake, which Messrs. Strong and Rolfe consider topographic evidence of the fault, and the sinks just described, it will pass directly through San Jacinto. (See Plate 6.)

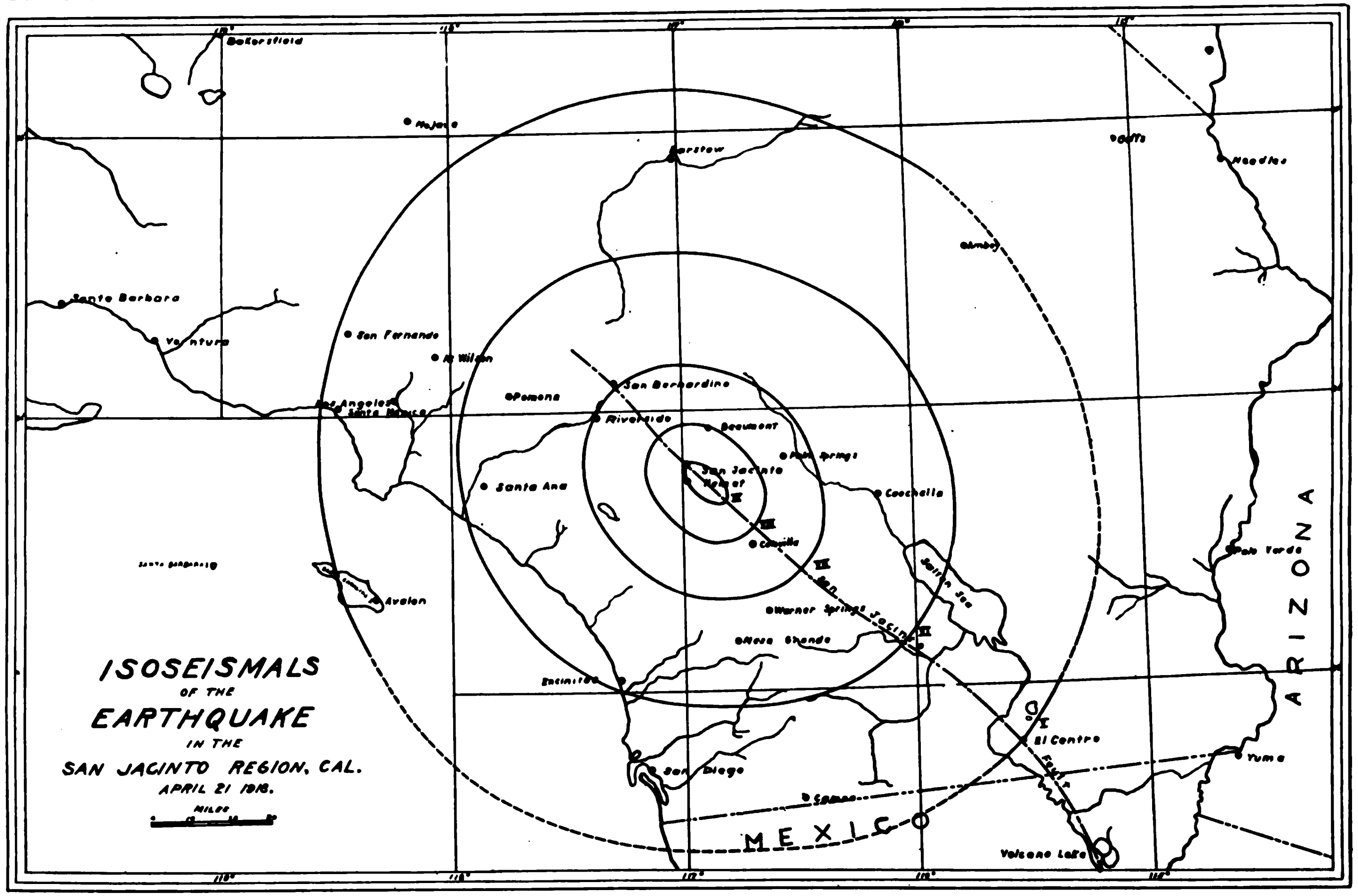


Fig. 3. Isoseismals of the San Jacinto, Cal., earthquake of April 21, 1918.

INVESTIGATIONS AT SAN JACINTO, HEMET, AND VICINITY

By HAMLIN AND TOWNSLEY

Damage to buildings.—The greatest damage caused by the earthquake was in the business district of San Jacinto. In the principal business block of the town but two buildings remained standing—a new concrete building and a frame building. The buildings wrecked were mostly brick or artificial stone of poor construction, or old frame buildings. Concrete buildings, substantial frame buildings, and well-constructed brick buildings were not seriously damaged. The damage at Hemet was considerably less than at San Jacinto. No buildings were completely destroyed and none of substantial construction were seriously damaged. The property loss at San Jacinto was estimated at $125,000 to $150,000 and that at Hemet not more than $75,000. Some of the damage wrought is illustrated in Plates 4, 7, 8 and Figure 10. Plate 9. There was also some damage to buildings at various places within a hundred-mile radius of San Jacinto. This damage consisted for the most part of broken plaster, chimneys, and plate-glass windows. The writer did not make any investigation of these damages outside of San Jacinto and Hemet.

Injury to people.—Several persons were injured in the wreckage, but no one was killed. It is fortunate that the shock came on Sunday afternoon when the business districts were deserted, otherwise it is probable that a number of lives would have been lost. The telephone office, located in a one-story frame building, was wrecked by the falling of the second-story brick wall of an adjacent building. The three telephone operators were imprisoned but not injured. (See Plate 7, Figure 6.) Mrs. George Koehler was buried in the wreckage of a second-hand store and rather seriously injured.[1] One man was thrown from his porch and sustained a broken rib. Several persons sitting on the ground at the time of the shock were unable to rise to their feet. Two miners were imprisoned by the caving in of a tunnel in a magnesite mine near Winchester, some ten miles or more southwest of San Jacinto. They were rescued uninjured.

Damage to roads, canals, etc.—The concrete road between Hemet and San Jacinto was cracked in thirteen places. This is a north and south road and the cracks were all approximately perpendicular to the

---

[1] As this sentence was being written an earthquake was felt by the writer in his office at Stanford University, California, 1918, August 3, $11^h30^m29^s$ a.m. ($6^h30^m29^s$ Greenwich Mean Civil Time). Intensity, III.

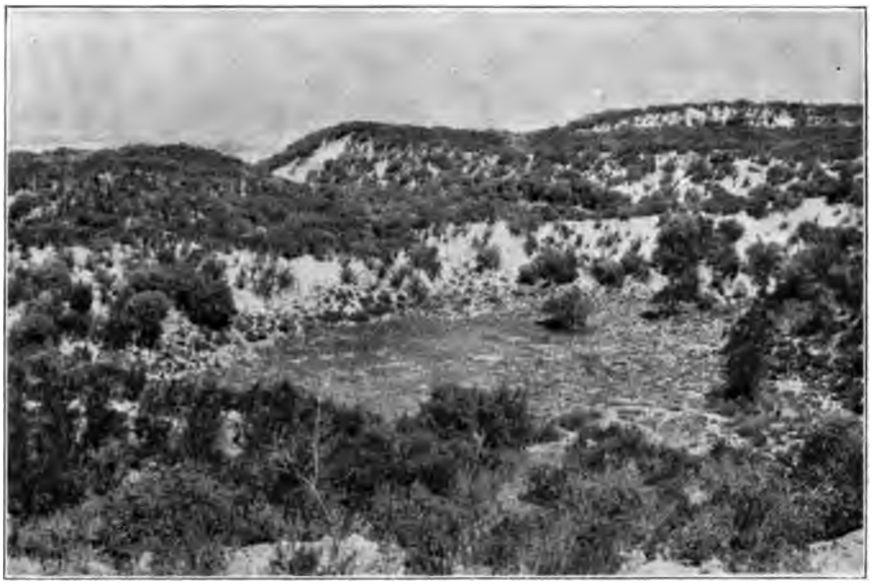


Fig. 4. Sunken area along San Jacinto fault trace, one mile east of Blackburn Ranch, between Bautista Canyon and San Jacinto River. Negative taken April 26, 1918, by H. H.

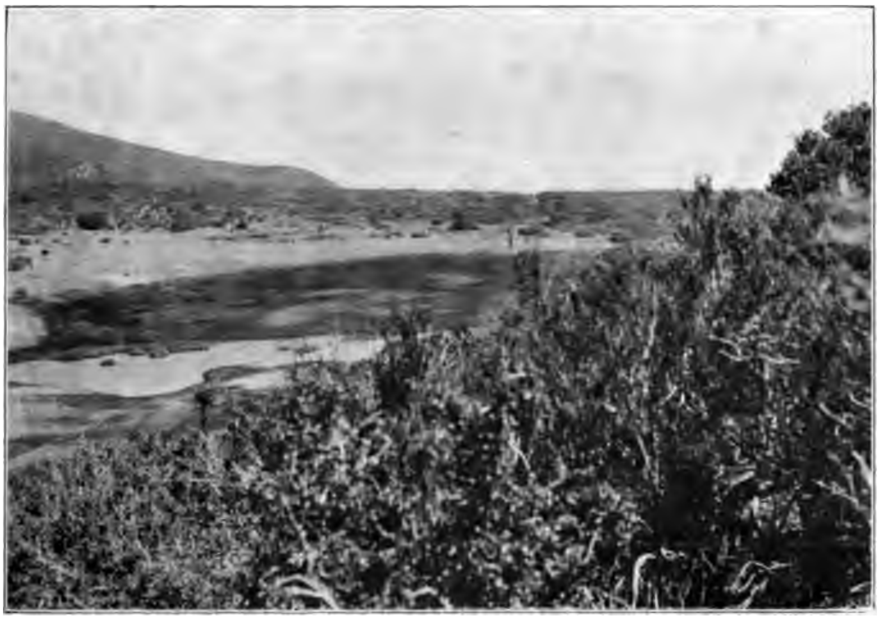


Fig. 5. Hog Lake. Looking south and showing spur of Thomas Mountain. Negative taken May, 1918, by F. R.

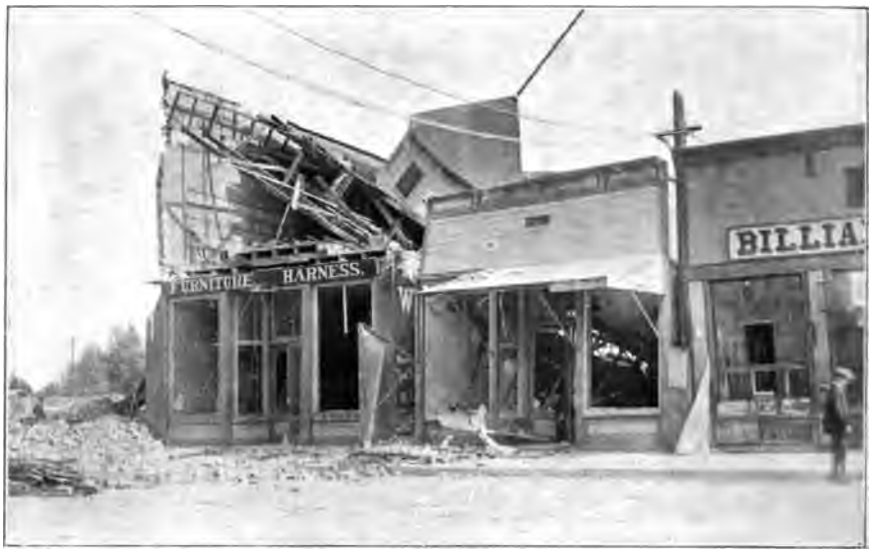


Fig. 6. Damage in San Jacinto, in same block as Plate 4. Center building is the telephone office. Negative taken April 24, 1918, by S. D. T.

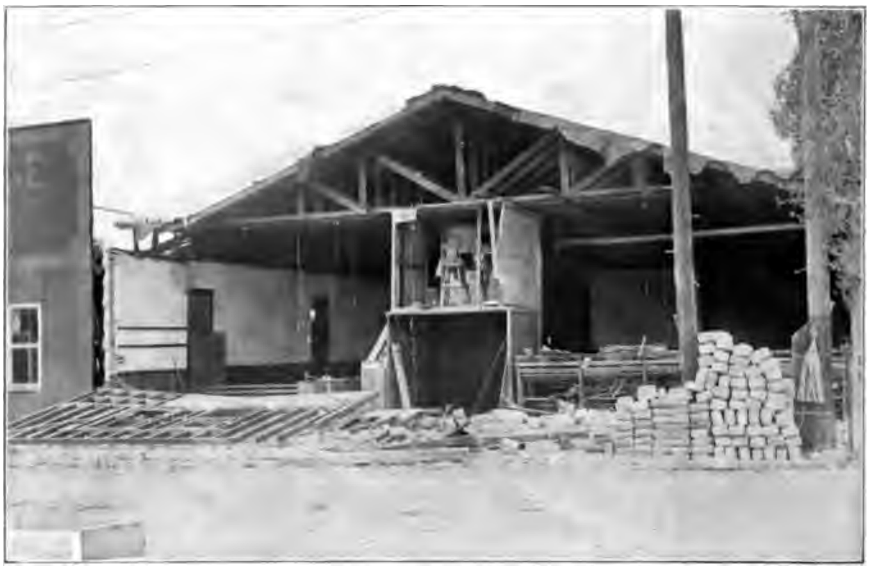


Fig. 7. Moving-picture theater, San Jacinto, built of artificial stone. Front of building fell into street. Negative taken April 25, 1918, by S. D. T.

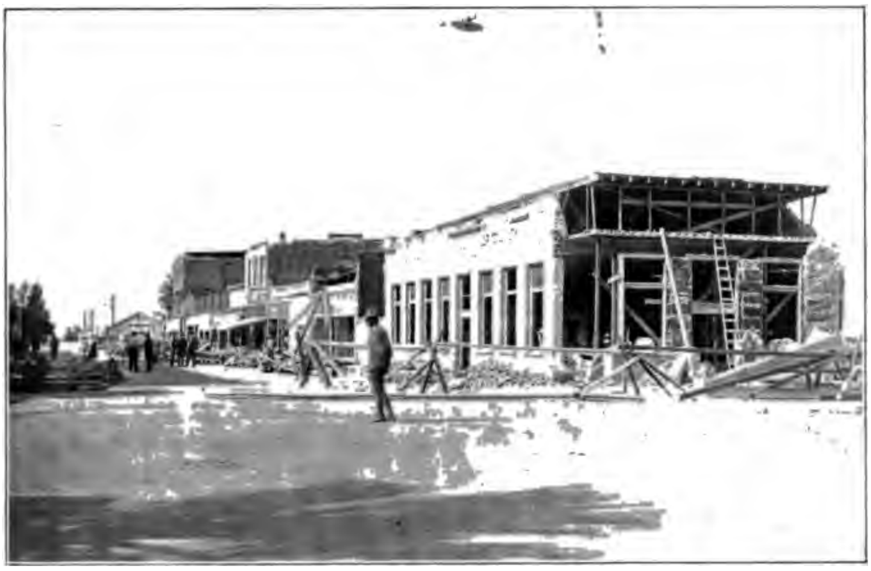


Fig. 8. First National Bank and other damaged buildings, Hemet, Cal. Negative taken April 24, 1918, by S. D. T.

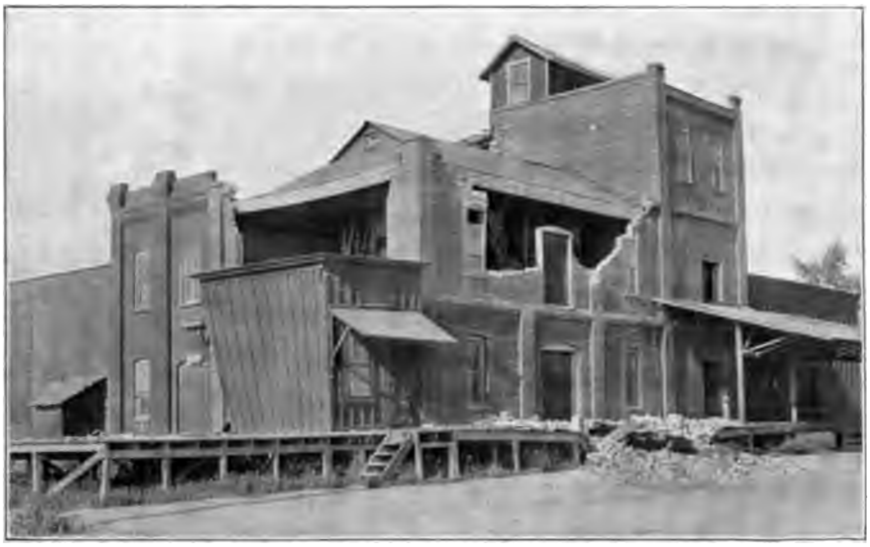


Fig. 9. Flour mill, Hemet, Cal. Negative taken April 24, 1918, by S. D. T.

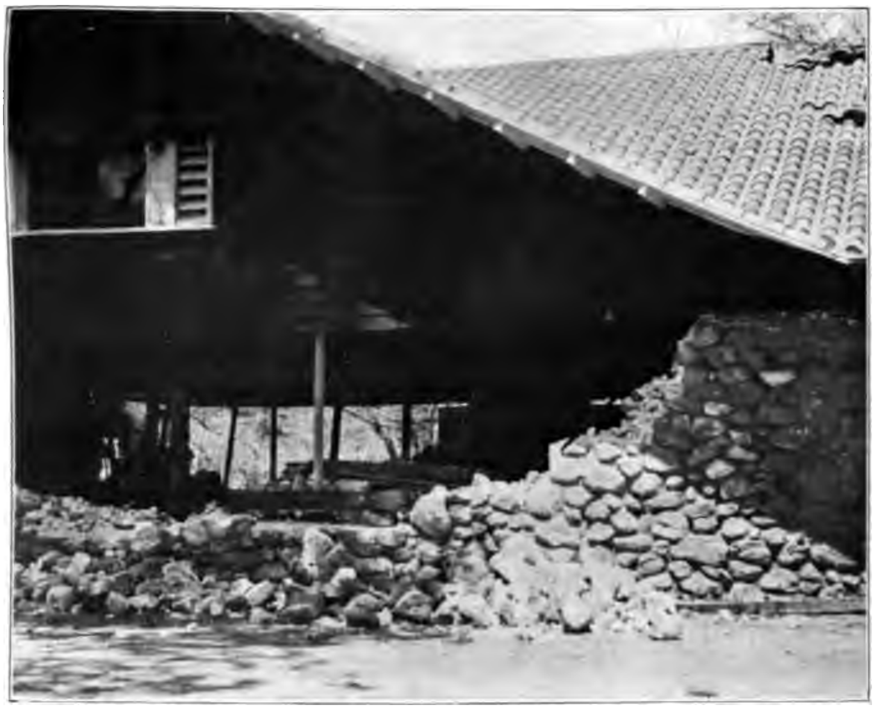


Fig. 10. Power house at Idyllwild, in San Jacinto Mountains, fifteen miles east of Hemet. Negative taken May, 1918, by F. R.

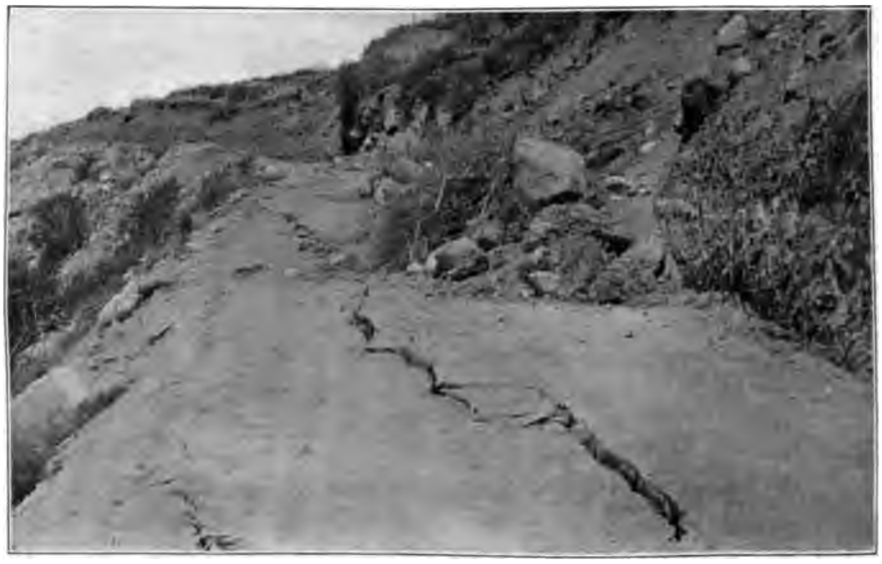


Fig. 11. Small landslide and crack in road, about ten miles east of Hemet. Negative taken April 25, 1918, by S. D. T.

direction of the road, probably occurring at the natural cleavage places in the concrete. No cracks were found in the earth at the sides of the road. In the main concrete road running northwesterly from San Jacinto there were several cracks of a much more serious nature. These were also perpendicular to the direction of the road. At one place about a mile northwest of the center of town the concrete was buckled and a section about three feet wide torn up. The alignment of the road was altered to the extent of about three inches. (See Plate 10, Figure 12.)

Concrete irrigating canals were broken at a number of places near San Jacinto and Hemet. At the Blackburn ranch the owner said that a concrete flume 2,000 feet long was broken, on an average, every six feet.

About a mile northwest of San Jacinto a silo, some thirty or forty feet in height and some twelve feet in diameter, was overturned, falling to the west. At a number of places in this same region live limbs were broken from trees. A cemetery is located about half-way between San Jacinto and Hemet. A detailed inspection was not made, but by driving around two sides practically all of the cemetery could be viewed. But one monument was seen to be overturned—a surprisingly small number when the severity of the shock is considered.

Ground cracks.—Cracks in the ground were found in four different localities, but it is believed that they were all due to the shaking and that none of them indicates a surface slip along the main line of the San Jacinto fault.

(a) The only cracks found in the immediate neighborhood of San Jacinto were in an alfalfa field on the ranch of A. McCleish, about a mile northwest of the center of San Jacinto, the field being adjacent to the road where the worst break was found as described above. There were several cracks ten to twenty feet long and approximately parallel to the direction of the road, and to the direction of the main San Jacinto fault as drawn by Dr. Arnold. His location of the fault shows these cracks to be very close to it. The ground here is low and flat—alluvial soil.

(b) About four miles southeast of San Jacinto and half a mile northwest of Vallevista numerous cracks were found along the banks of the San Jacinto river bed. My notes taken at the time read as follows: "Found many slides on banks of San Jacinto River; sandy soil cracked in places parallel to banks of river or to incoming gorges;

cracks in places as much as twenty feet back from banks." These cracks are close to the fault line, although probably due simply to the shaking.

(c) On the road to Strawberry Valley, about five miles east-southeast of Vallevista, numerous cracks were found in the mountain road. These had various directions and are believed to be due to the violent vibrations. These cracks were about two miles northeast of the fault line. (See Plate 9, Figure 11.)

(d) By far the largest and most numerous cracks were found on the mountain ridges east of the Blackburn ranch in the neighborhood of the sinks already described. From the ranch we followed up a winding ridge between two canyons. There were hundreds of cracks along the ridges—some over a foot wide. The cracks were mostly parallel to the direction of the ridges—some east and west, and some north and south. The largest cracks were found in the immediate neighborhood of the sinks. Two or three ridges which were only fifteen to twenty-five feet wide on top were all broken up—literally shaken to pieces. At a number of places the hard dried surface of the soil was broken into little patches half the size of one's hand or smaller.

In the reports received, cracks in the ground are reported at five other places, namely, Keen Camp, Hemet Dam, Idyllwild, Thomas Mountain, and Nuevo. Plate 10, Figure 13, is a photograph of one of the cracks in the region east of the Blackburn ranch.

Landslides.—A number of slides occurred in the mountains southeast of San Jacinto. The road from Hemet to Strawberry Valley was blocked in a number of places, the first serious slides being about five miles beyond Vallevista. Several persons who were spending the day in these mountains were obliged to leave their automobiles after the earthquake and walk home. Two men driving up the mountain in an automobile were swept off the road by a slide. They would have rolled down several hundred feet except for the fortunate circumstance that their car landed against a tree before the slide had carried it very far.

Many rocks and boulders were shaken from their places and rolled down the mountain sides, the larger ones destroying trees or anything else that lay in their paths. Figure 14, Plate 11, shows a granite boulder which rolled forty or fifty feet down the embankment of the San Jacinto River, and a hundred feet out into the bed of the stream. Figure 15 shows a landslide on the south side of the river in this same locality, on the Strawberry Valley road about four miles up from Vallevista.

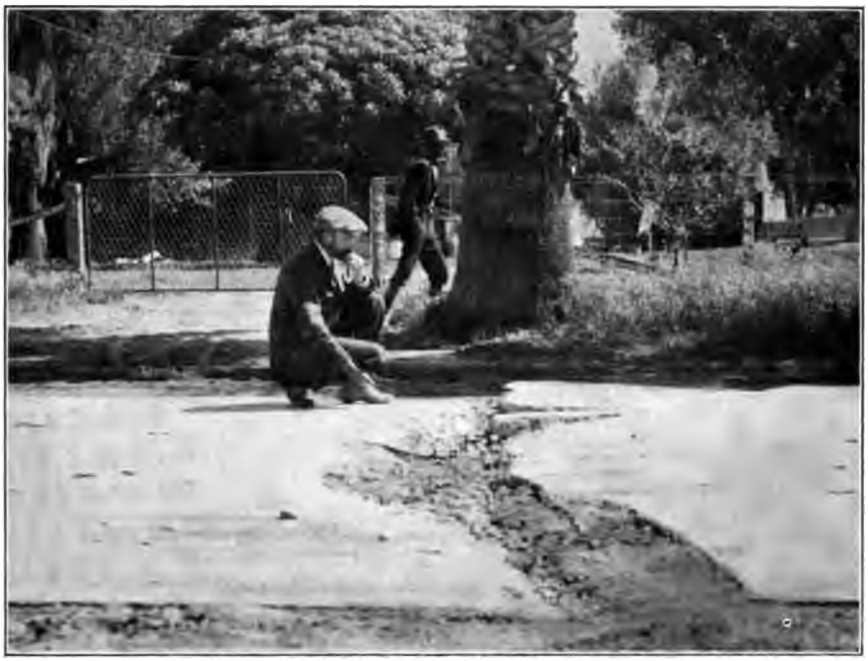


Fig. 12. Crack in concrete road, one mile northwest of San Jacinto. Negative taken May, 1918, by F. R.

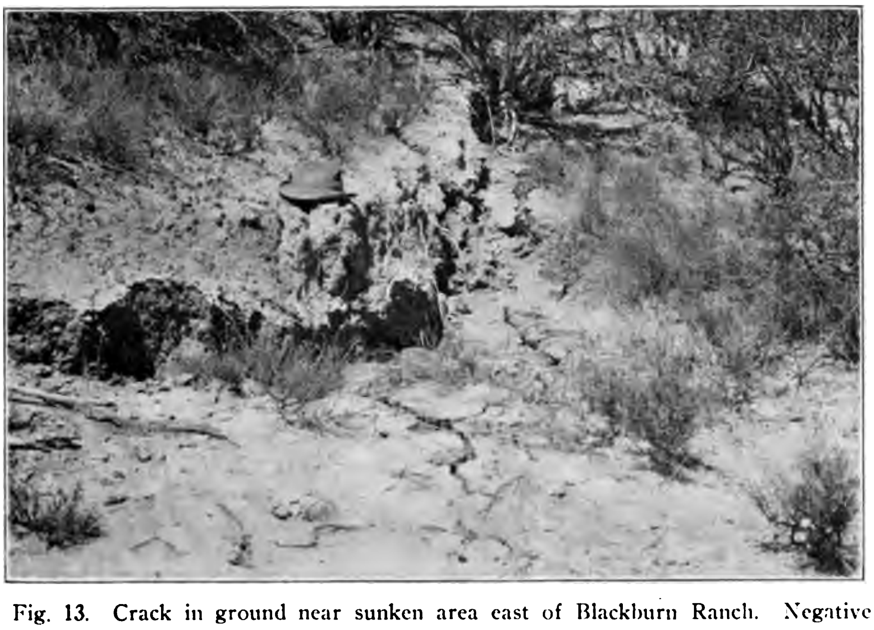


Fig. 13. Crack in ground near sunken area east of Blackburn Ranch. Negative taken April 26, 1918, by H. H.

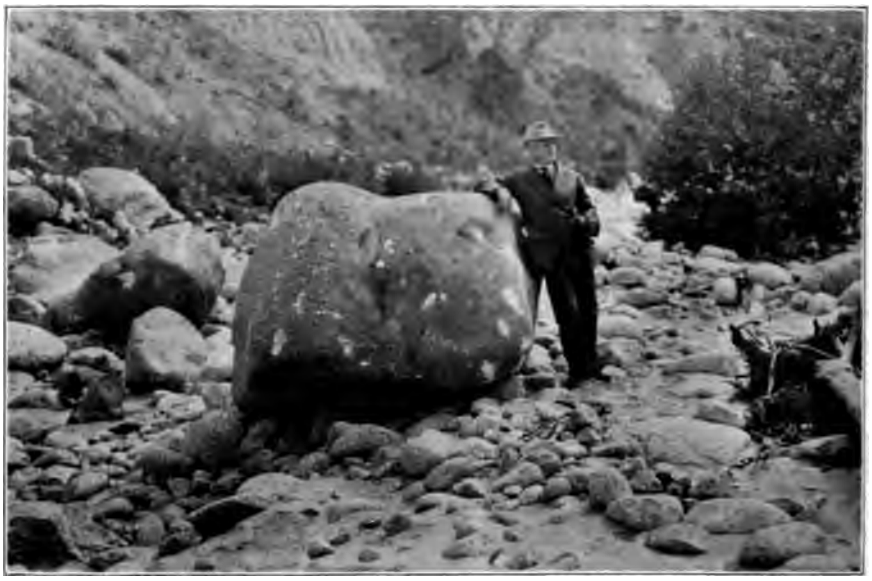


Fig. 14. San Jacinto River Canyon. Boulder dislodged from slope in the background. Negative taken April 25, 1918, by H. H.

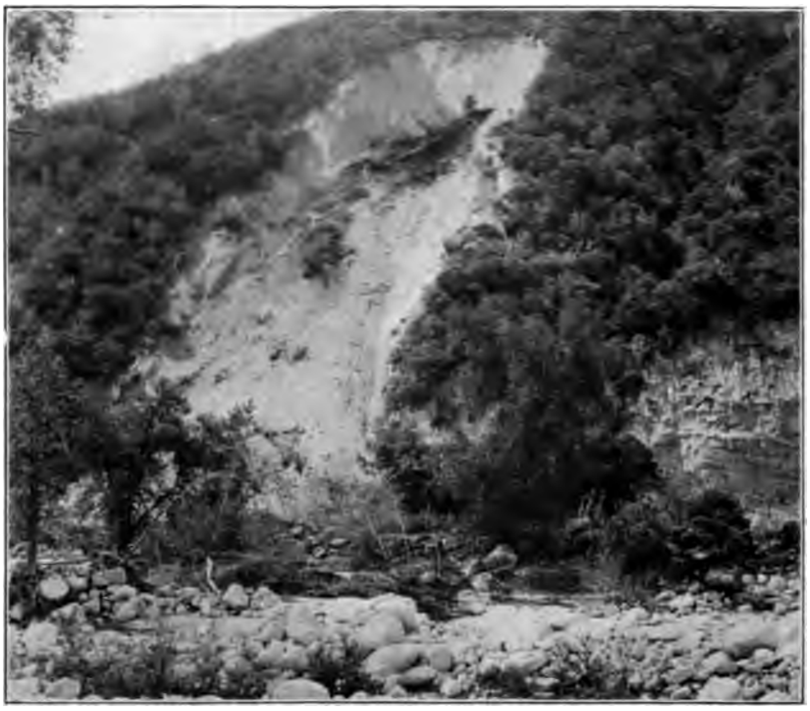


Fig. 15. Landslide on south side of San Jacinto River Canyon, about five miles southeast of Vallevista. Negative taken April 25, 1918, by H. H.

Immediately after the earthquake great clouds of dust were seen over the mountains, due to landslides, rolling rocks, and the shaking of the dry earth. (See Plate 12, Figure 16.) This photograph was taken by Mr. P. D. Mason, and his statement of his experiences is as follows:

"The photograph of dust clouds was taken Sunday, April 21, 1918, at about 3:30 o'clock in the afternoon, at a place about three or four miles east of Cabazon. With a party of friends I was riding along on the wagon road in an automobile on the north side of the railroad, when our attention was attracted to the dust rising from the ravines and hillsides on the east side of Mt. San Jacinto, which is, I should judge, about two and one-half or three miles from where the dust was rising. The driver of the car experienced a dizzy sensation. He stopped the car and we immediately got out. As we stepped on the ground we experienced a sensation which was not unlike that of stepping on the deck of a moderately large ship, while on a rolling sea. In addition to the rolling motion, we heard, or rather felt, a grinding sensation. Immediately thereafter we heard cracking noises like those of blasting, then the rumbling noises of the rock falling down the mountain side, ending with a thud, or dead sound like that of throwing stones into thick mud, too thick to splatter. The cloud of dust came mostly from the bottom of the ravines. There seemed to be two kinds of dust, one being much lighter than the other. The lighter may have contained some smoke, which we concluded may have been produced by the friction. The dust continued to rise for some time."

The extent of the shaking of the earth may be illustrated by an occurrence which happened at the Blackburn ranch. An orchard planted in sandy soil had been cultivated a few days before the earthquake, and furrows had been plowed between the rows of trees for the purpose of carrying irrigating water. The water had not yet been turned in when the earthquake came, and after the shock the furrows were almost completely obliterated.

Sand-craters.—On the farm of A. McCleish, one mile northwest of San Jacinto, where cracks were found in the alfalfa field, we discovered also a considerable number of small sand-craters, where the water had been forced out of the soil, forming small ponds. A large number of similar craters was also found in a field on the opposite side of the road. This was low ground and probably well soaked with water used for irrigation purposes. A photograph of three craters is reproduced in Figure 17, Plate 12.

Springs.—As is usual in the case of severe earthquakes, the flow of some springs and wells was reduced, while that of others was increased. At a number of places the temperature of hot springs is reported to have changed, but no quantitative measurements were obtained. Relief Hot Springs, on the edge of the valley, four miles north, northwest of San Jacinto, was visited, and we were surprised at the apparent lightness of the shock there. No damage was done, not even to a brick building in the process of construction.

At Swoboda Spring, located between two and three miles east of San Jacinto, across San Jacinto River and at the base of the mountains, no damage was done the hotel. A water pipe was broken and a coffee pot overturned.

These two springs are probably on the fault indicated on Dr. Arnold's map as the Hot Springs Fault. The comparative lightness of the shock at the two springs just mentioned seems to show conclusively that the slip which caused the earthquake did not occur on the Hot Springs Fault.

INTENSITIES AND ISOSEISMALS

One hundred and sixty-six reports of the San Jacinto earthquake were collected by Mr. Hamlin, five were added by Messrs. Strong and Rolfe, and three by the author. The reports were studied by Mr. Rolfe and the intensity of the earthquake determined by him at each place from the data given by each observer. The observer making the report is not asked to estimate the intensity of the shock, but merely to answer questions and relate his experiences. The estimate of intensities is then made by the person who works up the reports. The writer has also studied these reports and made an independent estimate of intensity for each. The isoseismals shown in Plate 5 are the result of the combined estimates of Rolfe and Townley, but the curves have been drawn by the author without consultation with Mr. Rolfe.

The observational data are summarized in Table I. No attempt has been made to give all of the data, and the usual columns for duration and sounds have been omitted.

Some difficulty was experienced in drawing the isoseismals, but it is believed that the curves drawn represent fairly well the data at hand. Some of the reports show an increase of intensity in the neighborhood of the Colorado River, which may be explained by the nature of the ground along the river or by the occurrence of a sympathetic shock. The report from Needles is the one that it is most difficult to

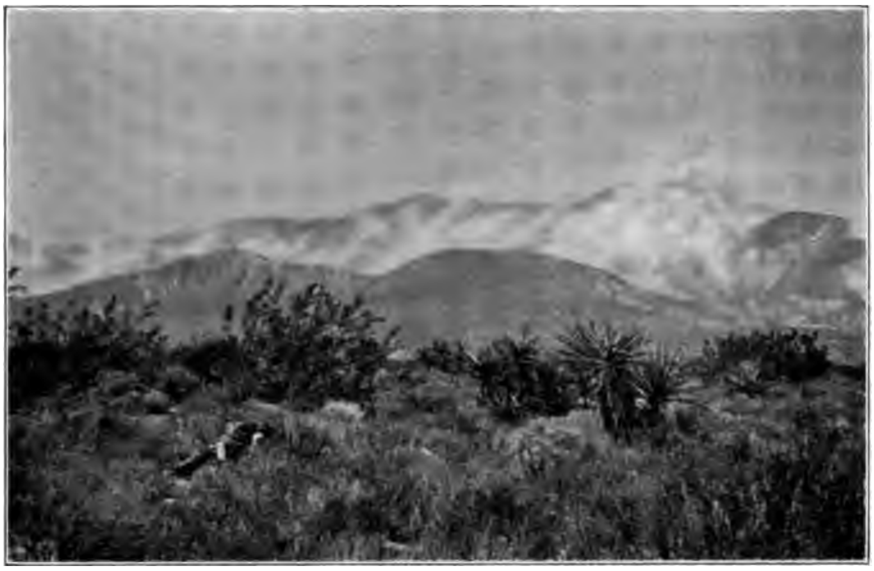


Fig. 16. Dust clouds over San Jacinto Mountains. Photographed immediately after the earthquake of April 21, 1918, by P. D. Mason, from a point three or four miles east of Cabazon.

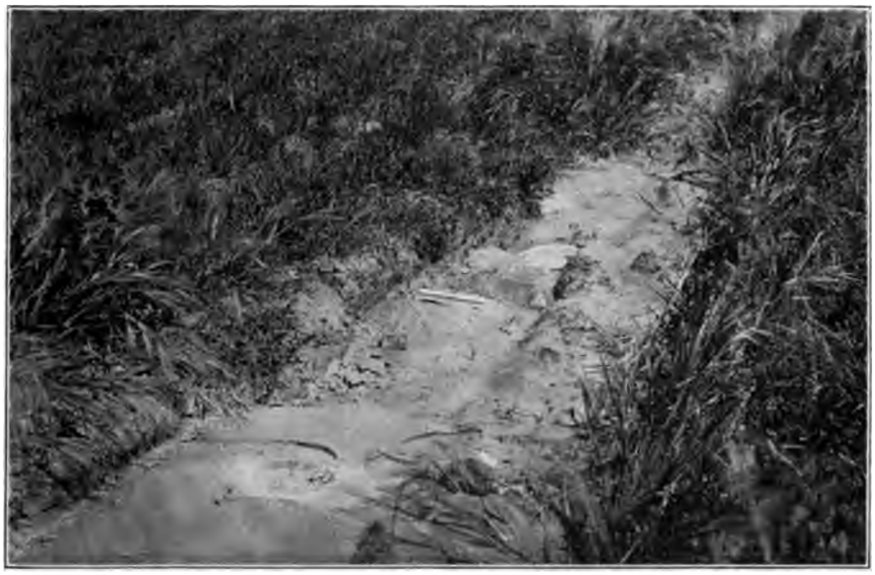


Fig. 17. Sand craters on ranch of A. McCleish, one mile northwest of San Jacinto. Negative taken April 25, 1918, by S. D. T.

TABLE I. SAN JACINTO EARTHQUAKE, CALIFORNIA, APRIL 21, 1918.

Place	Latitude N.	Longitude W.	Number of Reports	Intensity	Number of Shocks	Remarks
Acton	34°28′	118°12′	1	5	1	
Aguanga	33 27	116 52	2	7	3, 5 or 6	Many boulders rolled down mountains.
Alhambra	34 6	118 8	1	6	1	Three maxima.
Alamitos Bay	33 46	118 6	1	6	3	Three distinct shocks.
Amboy	34 34	115 45	1	6	1	
Anaheim	33 50	117 55	2	7	3, 1	Great difference in two reports.
Avalon	33 20	118 20	1	5+	3	No underground sounds.
Azusa	34 8	117 54	1	4	1	
Barstow	34 54	117 1	1	5	1	
Beaumont	33 56	116 59	2	7+	3, 3	
Beverly Hills	34 5	118 25	1	5	1	
Blackburn Ranch	33 41	116 51	1	9+	—	
Blythe	33 35	114 41	1	5+	2	
Brawley	32 59	115 33	2	5	1, 1	Automobiles in street moved back and forth 1 to 2 feet.
Brown	35 47	117 55	1	4+	1	
Cabazon	33 55	116 47	1	8	2	Two large railroad water tanks destroyed.
Calexico	32 40	115 31	2	5	1, 2	Automobile surged back and forth for 2 minutes.
Calipatria	33 8	115 30	1	6	1	
Camp Baldy	34 15	117 40	2	5+	2, 2	Twelve miles north of Upland.
Campo	32 36	116 30	1	5	1	
Carpinteria	34 25	119 31	1	4+	1	
Chatsworth	34 15	118 37	1	5	1	
Claremont	34 6	117 43	1	5+	1	
Coachella	33 43	116 11	2	7	1, 3	Great clouds of dust over mountains. Two picnickers injured by rolling rocks.
Coahuila	33 32	116 44	1	7+	4	
Colton	34 4	117 20	1	5	1	
Compton	33 54	118 13	1	6	2	
Cornell	34 7	118 47	1	4+	1	Fifty miles northeast Los Angeles.
Corona	33 53	117 35	1	7	2	
De Luz	33 27	117 21	1	7	—	Twelve or 14 shocks in 2 or 3 days.
Descanso	32 51	116 38	1	5+	1	
Domino	34 54	118 27	2	5	2, 2	
Dove Springs	35 26	118 1	1	4+	1	Thirty-two miles north of Mojave.
El Cajon	32 47	116 58	1	5	1	
El Modeno	33 47	117 48	1	6	2	
Elsinore	33 40	117 20	1	6	—	
Emedio	35 3	119 1	1	5	2	

TABLE I. SAN JACINTO EARTHQUAKE, CALIFORNIA, APRIL 21, 1918.—*Continued.*

Place	Latitude N.	Longitude W.	Number of Reports	Intensity	Number of Shocks	Remarks
Encinitas	33° 3′	117°18′	1	5	2	
Escondido	33 6	117 6	2	5	2, 2	
Fairmont	34 44	118 25	1	5	3	
Fallbrook	33 23	117 15	1	6+	1	Ground seemed to roll like waves.
Forest Home	34 6	116 53	1	6	1	Fifteen miles east of Mentone.
Fullerton	33 52	117 54	1	6	—	
Goff's	34 56	115 4	1	6	1	
Gorman	34 48	118 51	2	4+	1, 1	
Heber	32 43	115 32	1	5	1	
Hemet	33 45	116 58	3	9	1, 3, 2	Partial destruction of buildings. One observer reports 3 very distinct shocks.
Hemet Dam	33 40	116 42	1	7+	—	Small fissures in ground. Dust clouds over mountains.
Huntington Beach	33 40	118 0	1	6	2	Two shocks or two peaks of one shock.
Idyllwild	33 45	116 43	1	8+	many	Light cracks all over.
Imperial	32 51	115 35	1	5	1	
Jaw Bone Canyon	35 19	118 3	1	4	1	
Keen Camp	33 45	116 45	2	7+	1, many	One observer reports cracks in ground.
Kramer	34 59	117 35	1	4+	2	
Laguna Beach	33 32	117 47	1	6	1	Duration 1 min. 31 sec.
La Jolla	32 51	117 17	1	4+	1	
Lebec	34 50	118 51	1	4+	2	
Long Beach	33 46	118 11	1	5	several	
Los Alamitos	33 48	118 5	1	7	2	
Los Angeles	34 3	118 15	25	5.5	—	
Los Olivos	34 40	120 6	1	3	2	
Ludlow	34 43	116 10	1	5+	2	
Mecca	33 34	116 5	1	6+	—	
Mesa Grande	33 10	116 46	1	6	2	Loud roaring before shock.
Mojave	35 3	118 11	1	4+	1	Observer 17 miles north of Mojave.
Monrovia	34 8	118 00	1	6	1	
Mt. Lowe	34 13	118 8	1	4+	3	
Mt. Wilson	34 13	118 4	1	5	2	
National City	32 40	117 5	1	6	2	
Needles	34 50	114 36	1	7+	1	
Newhall	34 23	118 31	2	4	1, 1	One shock with slowing up at middle.
Nuevo	33 50	117 7	1	8	6 or 8	Fissures in ground.
Oceanside	33 12	117 23	1	6	2	
Ogilby	32 49	114 50	1	5	1	
Ojai	34 25	119 12	1	5	1	
Ontario	34 4	117 39	1	4+	1	
Oxnard	34 12	119 11	1	4	1	

TABLE I. SAN JACINTO EARTHQUAKE, CALIFORNIA, APRIL 21, 1918.—*Concluded.*

Place	Latitude N.	Longitude W.	Number of Reports	Intensity	Number of Shocks	Remarks
Palo Verde	33°26′	114°44′	1	6	1	
Palmdale	34 35	118 7	1	6	1	
Palm Springs	33 49	116 33	2	7	1, 1	
Pasadena	34 9	118 9	1	4	1	
Perris	33 47	117 14	2	7+	1, —	Man under floor of building reported sounds "like a giant bowling alley when the ball hits the pins."
Picacho	33 1	114 35	1	3	—	
Pine Knot	34 15	116 53	1	6+	3	Three separate shocks.
Point Loma	32 43	117 15	1	6	—	
Pomona	34 3	117 45	3	6.5	1, 2, 2	
Pot Holes	32 50	114 29	1	5	2	
Redlands	34 4	117 11	1	7+	—	Some chimneys shaken down.
Rialto	34 6	117 22	1	6	1	
Roosevelt	34 40	118 27	1	5	1	
San Bernardino	34 6	117 17	3	6.5	1, 1, 2	
San Diego	32 43	117 10	3	5	1, —, —	
San Fernando	34 17	118 26	2	5+	1, 1	
San Gabriel	34 5	118 6	1	6	2	Two distinct series of shocks.
San Jacinto	33 47	116 58	2	9+	15, 1	Total destruction of some buildings.
S'nJuanCapistrano	33 30	117 40	1	6+	3	
San Onofre	33 23	117 34	1	6	many	
Santa Ana	33 45	117 53	2	5+	1, 1	
Santa Barbara	34 25	119 42	2	5	4, 2	
Santa Monica	34 1	118 30	1	5	15 to 20	
Saticoy	34 17	119 9	1	4+	2	Person laying hose on lawn did not feel shock.
Saugus	34 24	118 32	4	5+	3, 1, 1	Standing automobiles moved back and forth
Seven Oaks	34 5	117 12	1	6+	3 or 4	
Taft	35 10	119 26	1	3	1	Another observer did not feel shock.
Thomas Mountain	33 37	116 41	1	8+	2	Observer thrown down.
Triunfo	34 9	118 9	1	4	3	
Tustin	33 44	117 49	1	5	1	
Venice	34 00	118 30	1	5+	3 to 4	
Ventura	34 17	119 17	1	5+	—	
Victorville	34 32	117 18	1	6+	3	
Voltaire	34 43	118 32	1	6	4	
Warner Springs	33 17	116 37	1	7	—	
Westminster	33 45	118 0	1	6	2	
Wildomar	33 36	117 16	1	7+	3	Three shocks in close succession.
Wister	33 18	115 40	1	6	1	
Yucaipa	34 5	117 5	1	6	4	Dust over mountains.
Yuma	32 43	114 37	1	3	1	

harmonize with the curves as drawn. Our estimate of intensity from the single report at hand is VII +. Besides the minor effects of swaying of buildings, rattling of dishes, etc., there were reported falling of plaster and chimneys and cracking of walls. The Weather Bureau published no report from Needles, but there are several reports from places in Arizona to the north and east of Needles which do not have nearly so high intensities. These are Mohave City V, Oatman V, Yucca IV, Kingman IV. These places are from twenty to forty miles from Needles.

TIME AND DURATION

In the reports received the time of the occurrence of this shock is reported from 3:05 to 4:30, the last probably in error by an hour. Fully ninety per cent of the times lie between 3:30 and 3:35. Apparently none of the times of beginning of the shock have been determined with astronomical accuracy. There is a great range in the reported duration of the shock or shocks. Some evidently have reported the duration of the main shock while others have included at least some of the aftershocks. The durations reported range from two seconds to ten minutes, with an average value of forty-seven seconds. Most of these of course are mere estimates and it is well known that only a very few people are able to estimate a short time interval in a way which even roughly approaches scientific accuracy.

Two observers determined the duration by their watches. Thomas A. ——————, at Laguna Beach, was eating lunch at the time of the earthquake, and writes as follows: "I did not rise during shock, but held on to the table. The moment the shock started I pulled out my watch and caught the exact duration of shock, which was one minute and thirty-one seconds." A. P. Wiley observed the duration at Palo Verde to be one minute, ten seconds. Lesser vibration undoubtedly continued for much longer than this. Mr. Frank S. Hewitt reported from Calipatria as follows: "An engineer out in the field was running a level at the time and informed me that by the spirit level the earth did not settle for about fifteen minutes."

DIRECTION

The questionnaire used by Mr. Hamlin does not ask for any information concerning the direction in which the earthquake waves travel, for the reason that it has been found by experience that data of this kind are not trustworthy. This point has been considered by Dr. Branner and others in preceding numbers of the BULLETIN.[2]

There are two reports, however, which give valuable information on this point. Mr. T. A. Miller, agent of the Santa Fe Railway at Goff's (about thirty miles west of Needles), reports as follows: "I had advice of the approaching earthquake several seconds before it actually occurred at this particular point, and was expecting and waiting for the shock. I was working on the train dispatcher's phone at 3:33 p.m. when I heard the operators at Newberry and Hector cry out that they were having an earthquake, that the building was rocking, and there was great disturbance. It must have been fully four or five seconds after this that I felt the shock approaching. In fact, it was so long afterwards that I thought we would not feel it. Newberry and Hector are about 100 miles west of this place. This experience plainly shows the shock traveled from west to east and was about four seconds coming that distance."

In a straight line, Newberry is seventy-five miles, Hector seventy-seven miles and Goff's 135 miles from San Jacinto. If we assume the origin of the disturbance to have been at San Jacinto, then the waves would reach Newberry and Hector at practically the same time, and this seems to have been the case. As Goff's is some sixty miles further from San Jacinto than the other two places, the disturbance would not reach there until some time later. Using four seconds, Mr. Miller's estimate of this time, we obtain a speed of 15 miles per second for the rate of propagation of the earth waves. This value is more than twice the known speed of propagation. This discrepancy may be explained in one of three ways. First, that the origin of the shock was not at San Jacinto; second, that the disturbances felt at Newberry and Hector and at Goff's did not originate at the same place; and third, that the observer underestimated the time. The last explanation seems the most probable. Except for the high intensity at Needles, we have no evidence that there was more than one origin of shocks. If there was a sympathetic shock near Needles, simultaneous with the shock at San Jacinto, then the disturbance would have been felt at Goff's before it was at Newberry and Hector, which is contrary to the facts. Of course, the sympathetic shock might have occurred after the main shock, but there is no evidence to support such a theory.

---

[2] *Bulletin Seismological Society of America*, **4**, 26.

An aftershock at 4:02 p.m. was reported by Mr. E. W. Tuttle, telegraph operator at Wister. The same shock was felt by the operator at Salton, between twenty-five and thirty miles northwest of Wister. The waves traveled in a general southerly direction, as may be seen from the following extract from Mr. Tuttle's letter: "The second shock, which occurred at 4:02 p.m., was very slight, being only a trembling. Agent at Salton called me about 4:01¾ p.m. and asked me if I had felt that shock that had just 'hit.' Said it hit him at 4 p.m. sharp. Just as he asked me I felt it."

SOUNDS

A study of the answers to the questions concerning "underground sounds" does not disclose any exceptional information. Thirty-seven per cent of the observers report having heard underground sounds either before, with or after the shock. Forty-nine per cent report that they did not hear any such sounds and fourteen per cent make no answer to the question—therefore negative by implication. These sounds are variously described as rumbling or roaring, faint or loud, etc. As is usual the sounds were heard by some people and not by others. A study of the geographical distribution of the places at which sounds were heard shows that they were not confined to any particular part of the area affected by the shock. Of the twenty-five observers in Los Angeles twenty-eight per cent reported underground sounds, sixty per cent reported none, and twelve per cent made no answer to the question.

At the Blackburn ranch, the observers reported that the sounds preceded the shock and all of the aftershocks, so that they always had warning of a shock before it was felt.

AREA AFFECTED

Taft, in Kern County, is the most northerly station from which Mr. Hamlin's observers reported the earthquake having been felt. The most easterly station was Seligman, Arizona, according to the U. S. Weather Bureau reports. The most southerly station from which a report was received was Campo, in San Diego County, near the Mexican boundary, but as the intensity was V at this place it is certain that the region of the sensible shock extended into Lower California. The most westerly station from which a positive report was received was Los Olivos.

Negative reports were received from Ozena, twenty-eight miles northeast of Santa Barbara; from Wheeler Springs, seventeen miles north of Ventura; and from Newberry Park, forty miles northwest of Los Angeles, where a party of four persons were sitting on the ground and the shock was not felt by any of them. Two reports were received from Taft; one observer felt the shock and the other did not. The U. S. Weather Bureau reports the shock as having been felt in Fresno, which is over one hundred miles further north than Taft, the most northerly place from which Mr. Hamlin's reports were received.

It does not seem possible to make an accurate estimate of the area over which the shock was felt. If we describe a circle with San Jacinto at the center, and Fresno on the circumference, we shall include an area of over 200,000 square miles, taking in large sections of California, Nevada, Arizona, Mexico, and the Pacific Ocean, from which no reports whatever have been received. If we describe a circle with San Jacinto as the center, and Los Olivos on the circumference, we shall include all of the territory covered by Mr. Hamlin's reports, and also the northern part of Lower California, a section of the Pacific Ocean, and a considerable desert region north of the Santa Fe Railway, from which no reports were received. On the other hand, this circle will not include all of western Arizona from which reports were received by the Weather Bureau. This circle has an area of about 110,000 square miles, and is, I believe, a fair estimate of the region over which the shock was felt.

INSTRUMENTAL RECORDS

This earthquake was of sufficient intensity to be recorded by seismographs in all parts of the world. Thus far reports have been received from Cambridge, Denver, Ottawa, Point Loma, and Washington, in North America; La Paz, Bolivia; Barcelona, Spain; Coimbra, Portugal; Zi-Ka-Wei, China, and Manila, P. I.

Taking those stations for which Δ, the distance of the station from the epicenter is given, and computing O, the time at which the earthquake occurred, by means of Table I, of Dr. Klotz's seismological tables,[3] we have the following tabulation:

---

[3] Publications of the Dominion Observatory, Ottawa, 3, No. 2.

Station	Δ km.	O
Barcelona	9640	$22^h32^m38^s$ G.M.T.
Cambridge	4040	24
Coimbra	9100	22
La Paz	7660	34
Ottawa	3600	24
Washington	3535	22 32 20
Mean		22 32 27

Taking all of the places except La Paz, the stereographic projection tables, No. 14, were used for locating the epicenter. The method gives a system of intersecting circles, but the places all lie in the same general direction from the epicenter, so the circumferences of the circles are too nearly parallel to give accurate results. All of the points of intersection, however, fall within a circle of 6 mm. radius, the radius of the projection circle being 10 cm. The mean point of intersection gives 116° west longitude and 33° north latitude for the coördinates of the epicenter. This is not in very good agreement with the results of field investigations, but, as stated above, the data are not such as to give a determinate solution of the problem.

AFTERSHOCKS

A large number of aftershocks was felt at San Jacinto, Hemet and the regions near these places. So far as known, no one kept an accurate record of the shocks. The high school cadets guarded the damaged property in Hemet during the night following the earthquake, and one cadet is reported to have felt twenty-seven shocks between 7:30 p.m. and 7:30 a.m. At the Blackburn ranch, Mr. Blackburn reported that he began counting shocks after retiring on the evening following the earthquake, and counted nineteen shocks in the short space of time before he went to sleep, and that he counted seven more the next morning in the short interval between the time he awoke and when he was ready to leave the house.

One observer reported that aftershocks were felt frequently up to May 5th. Three shocks were felt by the writer while in Hemet, as follows:

1918 April 24, 8:23 p.m. Intensity, IV.
April 26, 5:03 a.m. Intensity, III.
April 26, 7:05 a.m. Intensity, II.

(The above times are seven hours slow of Greenwich.)

HISTORICAL

On December 25, 1899, at 4:25 a.m., a severe earthquake was experienced at San Jacinto and many brick buildings were partially wrecked. From the account of Mr. Claypole,[4] I gather that none of the buildings were completely wrecked, but that the second stories of all the brick buildings were badly damaged. Many of these buildings were patched up after this shock, and that is probably one reason why they did not stand up better when the shock of April last came.

The testimony of persons who experienced both earthquakes is that they were of about the same intensity. In 1899, as well as in 1918, the intensity at Needles was very marked. Mr. Claypole quotes a report from Needles as follows: "A terrific shock of earthquake at 4:35 a.m. lasted fully thirty seconds, stopping all clocks. It broke glass and gave the town a thorough shaking. The vibration was from northeast to southwest." It should be noted that the time given in this report is ten minutes later than the time for San Jacinto.

The following abstract of newspaper accounts of the 1899 shock has been kindly furnished by Professor Harry Fielding Reid, of Johns Hopkins University:

"A severe earthquake occurred about 4:25 a.m., P.S.T., December 25, 1899, in the neighborhood of San Jacinto, California, and lasted from one to two minutes. The damage seems to have been limited to the neighborhood of San Jacinto and Hemet, the property loss being from forty to fifty thousand dollars. Brick buildings suffered most, nearly all of them being severely damaged. Frame buildings were not much affected, but furniture in them was overthrown. Walls of the county hospital were very badly damaged. The Highland asylum at Gables was cracked and its chimney shaken down. At Hemet, walls were overthrown or cracked and only two chimneys remained standing. Falling adobe walls at Soboba killed six Indians and wounded eight others. The earthquake was the severest ever felt at Riverside; some brick buildings were cracked and some chimneys overthrown. At San Bernardino, goods were shaken from the shelves. At Los Angeles, people were frightened and rushed into the street, but no damage seems to have been done. The shock was felt from San Diego to Seligman, Arizona. In the neighborhood of the origin, artesian wells flowed more freely after the shock, and two hot sulphur geysers are reported to have burst forth near Hemet. About ten miles west of the town of San Jacinto, in the low hills near the extinct volcano of that name, land about a square mile in area sunk from thirty to one hundred feet and was greatly broken up by many deep and wide cracks. The sinking seems to have been progressive, continuing for two or three months, and not to have occurred at once.

---

[4] E. W. Claypole, *American Geologist*, 25, 106 and 192, February, 1900.

"Thirty shocks were reported on December 25th and others on the following day. A later shock occurred March 18, 1900."

From the accounts, Dr. Reid estimates that the shock was felt over an area of 150,000 to 180,000 square miles. Mr. Claypole, who was in Pasadena at the time of the shock, and who visited San Jacinto a few days afterward, makes no mention of the sinking lands or of hot sulphur geysers. The intensities of the two shocks at San Jacinto, San Bernardino, Los Angeles and Needles, and the area over which they were felt, are almost identical, and the shock of 1918 seems to have been almost an exact repetition of that of 1899.

CONCLUSIONS

The investigations of the earthquake of April 21, 1918, show, and I think conclusively, that the shock was caused by a slip along the San Jacinto fault. No certain surface indications of this slip were found, but the hypocenter was probably not located at a very great depth, as the intensities at San Jacinto and vicinity were much greater than at any other place. The region of maximum intensity extended from about one mile northwest of San Jacinto to the region east of the Blackburn ranch in the Bautista Canyon, and possibly further—a total length of at least ten miles. There is some evidence, although I think not conclusive, tending to show that the intensity was greater near the extremities of this line than at intermediate parts. Some observers report two distinct maxima, which would seem to indicate that this was a twin earthquake, but a study of the distribution of the places where the shock was felt as single and as double does not reveal any proof of this. Others reported three shocks or three maxima, and it should, I think, be considered a complex earthquake, resulting fronr movement along the fault plane of several miles in extent.

THE EARTHQUAKE OF APRIL 21, 1918, IN THE SAN JACINTO MOUNTAINS

By Frank Rolfe and A. M. Strong

Investigations made immediately after the earthquake of April 21, 1918, in the San Jacinto Valley, California, made certain that the cause was a disturbance along the San Jacinto fault. The location of this fault has been described in considerable detail by Carl H. Beal in Bulletin No. 3, Vol. 5, of the Seismological Society of America, starting with its junction with the San Andreas fault near San Bernardino and extending in a southeasterly direction into Mexico. The purpose of the trip described in this paper was to examine the country along the fault in the mountain area southeast of the San Jacinto Valley, and to procure data of the intensity of the shock in the mountain valleys to the east and west of the fault line. Traveling was done by automobile with short side trips on foot to points along the fault.

The first stop was made at the Blackburn Ranch on Bautiste Creek, about eight miles southeast of Hemet. The fault is located in the hills about one and one-half miles to the east of the ranch house. The formation here is soft sandstone and shale, probably deposited in shallow lakes or possibly old valley fills, and the effect of the shock in cracking and generally shaking up the ground is very noticeable. This locality had been examined in detail by S. D. Townley and Homer Hamlin.

The general line of the fault from the Blackburn Ranch is southeast, roughly paralleling Bautiste Creek. As the road along this stream was not passable for an automobile, we took the main road south from Hemet, across the Saint John's grade, Lewis Creek and Wilson Creek Valleys, and into the Coahuila and Terwilliger Valleys just west of the fault line. This route took us some ten miles to the west of the fault. No signs of rock falls or other disturbance were visible along this road.

The shock was quite severe in the Coahuila and Terwilliger Valleys. Two stone houses and one adobe house were thrown down, and a number of chimneys were toppled over. At the Del Ollias store, near the old Coahuila Indian Reservation buildings, we were informed that practically everything was thrown off the shelves and that ground waves could be seen on the valley floor. In reporting to the U. S. Weather Bureau, the keeper of the store estimated the intensity as IX. The fault here is on the east side of the valley, along the slope of Thomas Mountain, over which the shock raised a cloud of dust described as being like a fog. Some rocks are said to have been shaken loose, and a light cloud of dust raised over Coahuila Peak to the northwest. The hot sulphur spring on the Indian Reservation has increased both in flow and temperature since the severe shock of April 21, 1918.

From a point in the road at the head of Bautiste Creek we went on foot to Hog Lake. The route followed was up a narrow ridge, soil covered but containing a large number of loose granite boulders from a few inches up to two feet in diameter. At a point about a mile southwest of Hog Lake we found a strip of ground about 300 feet in width on which every loose rock had been moved along the surface of the ground. On the surface of the ridge many of the rocks were overturned or rolled some distance down the hill; on the top they had been shifted from two to six inches in a direction parallel to the ridge fault and at right angles to the axis of the ridge.

Hog Lake is a small pond in a long, narrow, marshy sag on the west side of Thomas Mountain, showing all the marks of a sink along a fault line. The moist ground on the east side of the lake was cracked in several places, the largest crack being about six inches wide. In the sloping, marshy meadow to the south of the pond an area of about a quarter of an acre had settled at some time before this shock, according to the statement of one of the settlers. The cracks and the spalling of the banks to vertical faces, at one point six feet high, seemed recent.

It is about nine miles from Hog Lake to the shattered ground to the east of the Blackburn Ranch, part of the country being in granite and part in sandstone formations. The line of the fault northwest of Hog Lake is not plainly shown by the topography, but reported rock slides in the canyons to the northwest indicate its location. Southeast of Hog Lake the general line of the fault is plainly shown as a bench forming the foot of Thomas Mountain. Several springs, of which we were told but did not visit, probably mark its location. A settler who was at the springs at the time of the shock of April 21, 1918, reported that he was knocked down and the "red shank brush" on the hillsides shaken until it looked as if it would be pulled out by the roots.

The road from Terwilliger Valley to Hemet Lake Valley crosses the fault near the foot of the Hamilton grade, some six miles southeast of Hog Lake. At this point we found a small gravel knoll, opposite the mouth of Hamilton grade, to be badly shattered. Hamilton Creek Canyon is a narrow canyon about one and one-half miles long. It has been cut or broken through granite rock along the line of the fault. A few small rock slides and fallen boulders were the only signs of the recent shock that we observed along its course. At the upper end the canyon opens out into a flat basin of sandstone known as Burnt Valley. On the west side of the creek, just where it enters the valley, there is a spring in a narrow trough on the side of the hill. This trough is several hundred yards in length and water seems to come up all along it, as the bottom is sodded over for a width of fifty feet or more. This is undoubtedly another old sink similar to Hog Lake, but smaller; there were no signs of recent ground movement.

The intensity of the shock of April 18, 1918, in the eastern part of the Terwilliger Valley may be judged from the following information obtained from a settler in Sec. 12, 8 S., 3 E. A small, well-built chimney was set about two feet out of line but not overturned or broken. A poorly built stone fireplace and chimney were wrecked. Dishes were thrown from shelves, milk thrown out of pans, and a small water tank half emptied by the water splashing out.

Leaving this locality, we crossed the Hamilton grade into the southerly end of the Hemet Lake Valley. At Kenworthy the shock of April 18, 1918, was heavy. Everything on shelves was thrown off; the light frame buildings were racked but not damaged; men working under a wagon were unable to get to their feet; clouds of dust formed over the mountains on both sides of the valley, that over Thomas Mountain being the heaviest; a large nearby spring increased its flow.

Our last visit to the fault line was at the head of Horse Canyon, four miles in an air line from the sink on Hamilton Creek. On the trip down the canyon the only signs of the shock were a few displaced boulders. The volume of the small streams seemed to have been increased, a fact which we attributed to the recent shock, although we had no other data to verify this conclusion.

Expecting to find the fault on the west side of the main canyon, we examined it with field glasses, but failed to find anything in the topography indicating its exact location. The bottom of the main canyon and the west side is granite; the east side, extending up into Vandeventer Flats, is sandstone. We returned up a narrow sandstone ridge, the top of which we found to be shattered and cracked in much the same way as the ridges near Blackburn ranch. This place is one and three-quarters miles to the east of the line of the fault as determined by Hog Lake and Hamilton Creek. This point was as far south as we could get on this side of the mountains. We returned by Hemet Lake and Strawberry Valleys, and Strawberry grade to Hemet, the route taking us from four to six miles east of the fault line.

At Hemet Lake the caretaker told us that no damage had been done to the high masonry dam at that place—not even a crack in the plastering. Although the shock at this place was severe, neither the caretaker nor his wife, both of whom were looking at the lake when it occurred, observed any wave action on its surface. Cracks appeared in the moist ground, and a large spring dried up; the flow of the spring, however, is gradually coming back.

At Keen Camp the shock was severe, but the only damage was the cracking of rubble chimneys. In Strawberry Valley a good deal of damage was done by the falling of chimneys and foundation walls, due largely to the character of the mortar in which the rubble was laid. All the trails around San Jacinto and Tahquitz Peaks and the mountain roads were damaged by rock falls and the cracking of the fills on the outer edges. Dead limbs were shaken from trees. After the big shock fine cracks were found in the ground, but they had filled with dust before our arrival,—about three weeks after the shock.

Throughout the entire district visited the aftershocks had been noticeable, and we experienced slight rumblings and shocks two weeks after the first heavy shock. We spoke with several persons who had felt, in nearly the same spot, the heavy shocks of 1918 and 1899. Some reported that of the earlier date the greater; others thought it not so great as the latter date; all agreed that there was not much difference in the intensities of the two shocks. The conditions at Blackburn Ranch and at Hog Lake indicate that there was a greater ground movement in 1899 than in 1918.

We found no evidence of actual displacement along the fault due to shocks of recent date. While the location of the old fault plane is evident near Hog Lake and Hamilton Creek, at other places all signs of it have disappeared. At a number of places in the district examined the fault passes under slightly tilted beds of sandstone and shale. Our limited observations failed to show any signs of displacement in these beds, whose deposition probably followed the period of great activity of the fault. The most noticeable effects of the shock along the general line of the fault were found on the tops of narrow ridges, seen in three different places, the course of the ridge in each case running about at right angles to the fault line. These areas were comparatively small and they did not seem to be necessarily on the direct line of the fault.

All observers reported that the shock caused clouds of dust to rise along the sides of the hills and canyons; we found no signs of large rock slides or marked displacements to cause this phenomenon, which seemed likely to be due to a general shifting and cracking of the ground surface, and was more evident in the territory to the east of the fault. Rumbling sounds seemed to have accompanied many of the shocks. In general there was nothing to indicate that the shock was more severe in the mountain area to the southeast of the San Jacinto Valley than in the valley itself.

Acknowledgment is due to Mr. M. M. Hays for assistance on the trip; to Dr. Ralph Arnold and Mr. Homer Hamlin for advice and coöperation. Dr. Arnold also placed his automobile at our disposal. The residents of the section visited received us kindly and freely gave us much information about the shock. Owing to the limited time and the unfavorable weather, our examination of the country was not as complete as we desired.

TOPOGRAPHY AND FAULT SYSTEM OF THE REGION OF THE SAN JACINTO EARTHQUAKE

By Ralph Arnold

Location and Topography

The region most affected by the earthquake of April 21, 1918, is included in the same belt of faulting and disturbance as that embracing the territory of maximum shock of the earthquake of June 22, 1915. This belt is 175 miles long and extends from the eastern end of the San Gabriel Mountains in a southeasterly direction along the southwestern flank of the San Jacinto Range, out into the southern end of the Imperial Valley, and thence for an unknown distance beyond the international boundary into Lower California. It includes the eastern end of the Cucamonga Valley, the San Bernardino, San Jacinto, Terwilliger and San Felipe valleys and the drainage areas of San Jacinto River, Bautiste Creek and Horse Canyon. The northern end of the region may be reached from the San Jacinto branch of the Santa Fe Railway; the southern part by automobile road from San Jacinto, San Diego, or the towns in southern Imperial Valley.

For the earthquake of April 21, 1918, the region of maximum disturbance was confined almost wholly to that part of the belt lying within the San Jacinto quadrangle and extending from the northwestern end of the San Jacinto Valley to Horse Canyon, east of the Terwilliger Valley, while for the catastrophe of June 22, 1915, the epicentrum was farther south, between El Centro and Calexico. The region of greatest disturbance in the 1918 earthquake is the one principally discussed in the present paper.

The San Jacinto Valley, topographically speaking, is long and flat-bottomed, and lies at an elevation of between 1400 and 1500 feet above sea level at the western foot of the San Jacinto Mountains. Its northwestern half is narrow and parallel-sided, its southern part expanded toward the southwest. The northeastern limit of the valley is practically a straight line running 47° east of south along the base of the mountains. The valley is terminated on the northwest by the range, lying south of the San Bernardino Valley, which in-

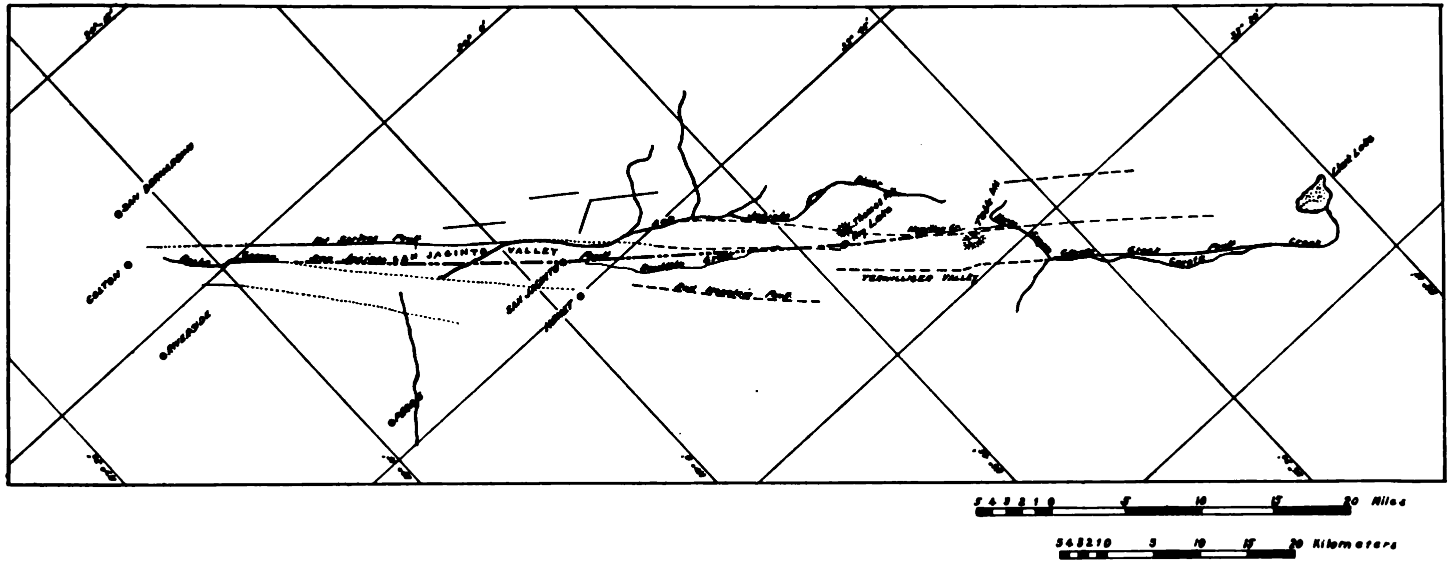


Fig. 1. Map of the San Jacinto fault zone, San Bernardino, Riverside, San Diego and Imperial counties, California. Location of main San Jacinto fault from Reche Canyon to Horse Canyon by Homer Hamlin, Frank Rolfe, A. M. Strong and S. D. Townley. Other geology and topography by Robert T. Hill.

cludes the Box Springs Mountains. The units of this range show the characteristic relief of the granitic rocks of which they are composed. According to Hill, the San Jacinto Valley is flanked on the northeast largely by characteristic bad lands topography. The southwestern edge of the valley is determined by several more or less isolated ridges and groups of granitic hills.

From the southeastern end of the San Jacinto Valley the zone of maximum disturbance follows the high ridge between Bautiste Creek and the South Fork of the San Jacinto River, thence along the southwestern flank of Thomas Mountain (elevation 6823 feeet) and the northeastern border of the elevated and westerly-sloping Terwilliger Valley, and so on into the mountainous region at the head of Horse Canyon. From here it passes southeastward, across an elevated mesa and then downward into the low valley extensions of what Hill calls the San Felipe Embayment, which lies at about sea level. For practically the entire distance southeastward from the San Jacinto Valley the region is barren and uninhabited, so that records of disturbances throughout its extent must be obtained largely through the more or less isolated but lasting surface evidence produced by the earthquakes.

Geology and Structure

The geologic discussion in this paper is based on the field work of Messrs. Robert T. Hill, S. D. Townley, Homer Hamlin, Frank Rolfe, and A. M. Strong. Through the courtesy of Dr. George Otis Smith, Director of the U. S. Geological Survey, that part of the manuscript and map of Hill's "Geography and Geology of Southern California" now being published by the Survey as a "Professional Paper," was made available to the writer. Most of the statements regarding the distribution of the surface formations and the mapping and distribution of the faults, with the exception of the location of the main San Jacinto fault, are taken from Hill's paper. Use has also been made of the information contained in Beal's[1] description of the June 22, 1915, earthquake throughout this same region.

In many regions the character of the formations takes precedence in point of interest over the structural relations of the rocks. Here it seems to the writer that the reverse condition is true, as the structure absolutely dominates the situation.

---

[1] Beal, Carl H. The Earthquake in the Imperial Valley, California, June 22, 1915. *Bulletin of the Seismological Society of America*, **5**, 130-149, September, 1915.

The rocks of most of the territory covered are chiefly crystalline schists, gneisses and granites, but immediately adjacent to the disturbed belt blocks of Tertiary sedimentaries have been faulted into the crystallines in a most abrupt manner.

The dominant structural feature of the region under discussion is the San Jacinto fault zone, which consists of one or more lines of displacement extending from the San Bernardino Valley in a southeasterly direction beyond the Mexican boundary. The zone is an offshoot of the Great Fault Belt, which extends from Point Arena to San Gorgonio Pass, and, to be more exact, is the southeastward extension of the Lytle Creek fault which is mapped and described by Hill.

The main San Jacinto fault as traced by Hamlin, Townley, Strong, and Rolfe, and shown on the map by a heavy line, passes out of the San Bernardino Valley through Reche Canyon, southeast of Colton, thence southeasterly down through the center of the San Jacinto Valley, probably coincident with the main road from Casa Loma, on through the center of the town of San Jacinto, thence up the small canyon which begins about one and one-quarter miles southeast of the village of Vallevista, on into the hills through the escarpment at the head of the canyon east of Blackburn Ranch, thence through the headwaters of Horse Creek (an eastern branch of Bautiste Creek), thence through Hog Lake, up Hamilton Creek, through the very pronounced fault topography at the spring west of Burnt Valley, passing Table Mountain on the northeast, and, finally, across into the region of the headwaters of Horse Canyon. From Horse Canyon the fault, according to Hill, passes southeastward through the table land northeast of Coyote Creek, and eventually loses its identity under the valley filling northwest of Clark Lake.

It seems to the writer that the evidence suggesting the presence of this fault through the middle of the San Jacinto Valley is good, as it would, in a measure, account for the topography of Park Hill, northeast of Hemet, and the unusual disturbances through the middle of the San Jacinto Valley itself during the earthquake of April 21, 1918.

According to Hill, the main San Jacinto Fault leaves the San Bernardino Valley and passes into the hills through a small canyon just south of Mound City, three and one-half miles east of Colton, and is distinctly traceable along the northeastern edge of the San

Jacinto Valley to a point east of Casa Loma. From Casa Loma southeastward, Hill shows the fault present but masked by the valley filling to a point at the foot of the hill one and one-half miles southeast of Vallevista. Southeastward from here its course through the mountains between Bautiste Creek and the San Jacinto River, to its southern end at the northwestern corner of the Ramona Indian Reservation in the north end of the Terwilliger Valley, is the same as that traced by Strong and Rolfe, except that the latter carry it through Hog Lake, while Hill places it considerably west of this lake. As Hog Lake is one of the most characteristic forms of fault topography in the entire region under discussion, it seems reasonable to locate the fault trace through this depression.

Hill maps another fault, beginning at "B. M. 2062" at the mouth of the San Jacinto River canyon and extending southeasterly up the South Fork of the San Jacinto River, thence along the southwestern face of Thomas Mountain, to Hamilton Creek, and thence following the course of the San Jacinto fault as traced by Strong and Rolfe. Hill also maps a third fault, called the Coyote Creek fault in this report, directly paralleling the southeastern portion of the San Jacinto fault but two and one-half miles farther southwest. The Coyote Creek fault starts in the headwaters of Bautiste Creek, passes through the center of Terwilliger Valley, through Coyote Canyon, thence along the northeastern edges of Collins and Borego valleys and Borego Mountain into the valley southeast of this mountain.

Hill extends the Reche Canyon fault, which the writer believes is part of the main San Jacinto line, through the hills at the northern end of the San Jacinto Valley; thence it is marked as questionable, owing to the valley filling, along the southwestern edge of the San Jacinto Valley where it terminates the various granite masses which more or less imperfectly define this side of the valley. A continuation of this fault, shown as the Red Mountain fault on the map, is shown as passing along the northeastern flank of Reservoir Butte, three miles southeast of Hemet, thence through the hills, of which Red Mountain is a dominating peak, more or less roughly paralleling Bautiste Creek, to the northwestern end of the Terwilliger Valley, approximately two miles southwest of the northwestern end of the Coyote Creek fault.

Minor faults are also shown on the southwest side of the mountains immediately northeast of the Box Springs Mountains. These faults are questionably continued southeasterly to the middle of the Lakeview Mountains, roughly paralleling the fault described as passing along the southwestern edge of the San Jacinto Valley.

Short faults are also shown paralleling the northeastern edge of the San Jacinto Valley, distant three miles from the valley, beginning at the vicinity of Potrero San Jacinto Nuevo, extending northwesterly for four miles and southeasterly for twelve miles. A fault is also indicated as passing between the southeastern end of Hemet Valley and the northwestern end of the valley southwest of the middle portion of the Santa Rosa Mountains.

It is the writer's belief that the fault which Hill maps as bounding the San Jacinto Valley on the northeast, and which Hill considers part of the main San Jacinto fault, passes about one and three-quarters miles east of San Jacinto along the base of the hills, through the hills west of the lower reaches of the San Jacinto River, and thence into the canyon of the south fork of the same river, thence along the upper part of the northeastern flank of Thomas Mountain, thence along the southwestern side of the southeastern extension of Hemet Valley, through the uppermost reaches of Horse Canyon, and so on down into the desert region north of Clark Lake. The writer has called this fault the Hot Springs fault, for purposes of description in this paper, the name coming from Relief Hot Springs, a point on the fault four miles north of San Jacinto. Strong and Rolfe found a point of excessive disturbance in one of the upper forks of Horse Canyon about one and one-half miles southeast of Lookout Mountain, which would fall in line with the location of the fault as described above. In general, this fault parallels the main San Jacinto fault, as described in this paper, throughout practically its entire length from the San Bernardino Valley to the desert region west of Salton Sea, and, in connection with the Coyote Creek fault, gives three almost uniformly parallel lines for a distance of many miles. Such a system accounts for the topography and geology of the San Jacinto Valley and connects with the three faults described by Hill as passing through the hills southeast of Colton.

REMARKS ON THE SONORA EARTHQUAKE—ITS BEHAVIOR AT TEPIC, SONORA, ETC.

By BERNARD MACDONALD

I have listened with great interest to Mr. Staunton's recital[1] of his personal experience with the Sonora earthquake in the underground workings of the Tombstone mines. My observation of the "doin's" of this earthquake, while it was in actual operation, was at Tepic (?) or Tepachi (?), a little farming village situated six miles south of Cumpas, on the wagon road between this latter town and Moctezuma, in the state of Sonora, Mexico. Tepic is distant approximately 120 miles south of Tombstone, Arizona.

The earthquake occurred in the year 1887, on the 3rd of May (the "fiesta de La Cruz" of the Mexican miners), at 3:20 in the afternoon. At this time I was superintendent of the Santa Ana Mining Company, then engaged in equipping the "Santa Ana" with pumping and hoisting machinery. The Santa Ana is an old mine with a bonanza record (according to Ward's history of Mexico), and is situated about fifteen miles west of Cumpas.

On the day of the earthquake I left the mine in the morning and came to Cumpas to hurry out some mining machinery that had arrived there the day before by teams from Fairbanks, Arizona, which at that time was the nearest railroad station. On reaching Cumpas, I found that our teamsters, who were mostly Arizona Mexicans, had caught the spirit of the miners' festival and were too much "enthused" to be induced to start for the mine that day. The festivities of the day were staged to take place at Tepic that afternoon and night, so I went there to see the celebration.

An outdoor public ball had opened in the afternoon under an arbor erected on the plaza, and the people were dancing or promenading around to the music. The day was one of those bright, warm, sunshiny days peculiar to Mexico, and the sky was unmarred by a cloud. I was sitting on a bare tree fallen by the side of the plaza, contemplating the gay colors of the dancing mass in the checkered sunbeams falling through the green arbor overhead and making a harmonious blending with the surrounding tropical scene. I have often thought since, in reflecting on this scene, how impossible it would have been to imagine then that in a few seconds that gay gathering would be scattered throughout the town in little groups of cowering suppliants asking for celestial intervention and protection. But such was the case, nevertheless. At 3:20 the thrum, thrum of the music, the swish, swish of dancing feet, and the gay chatter of the promenading crowd were interrupted by *bump, bump, bump,* three distinct, tremendously loud subterranean knocks, coming about one second apart. These bumps seemed to "knock the props" from underneath the plaza, leaving the ground a swaying, vibrating, creaking shell, accompanied by an indescribable conglomeration of crushing, grinding, and rumbling noises. The ground oscillated, sunk, rose, and trembled, sending up into the air immense puffs of acrid, blinding dust as if from hundreds of cyclopean bellows. The crowd was instantly panic-stricken and ran hither and thither, falling and sprawling as they went. The whole cataclysmic occurrence, which seemed an *earthcrush* rather than an earthquake, appeared to be located immediately underneath the plaza, and, to escape being swallowed up, I ran, like the others, toward the uphill side of the town. As I started to run I saw the three earthwaves rolling across the plaza toward me. *These waves seemed to be two feet high, about twenty feet apart, and moved as rapidly as the incoming waves along the seashore.*

---

[1] *Bulletin of the Seismological Society of America*, **8**, 25.

At the risk of throwing suspicion on the credibility of the statement in the last sentence, I have underscored the remarks because the phenomenon of the solid rocky surface wrinkling up into waves, traveling rapidly (westward) across the plaza and smoothing out again, is so physically improbable that I want it to stand out as it then appeared to me.

In running away from the plaza I fell across one of these waves, but lost no time in resuming the flight. When I had reached the distance of seventy or eighty yards up a street running out from the plaza, the crashing and rumbling sounds had subsided to a subdued shiver. I turned around to see the expected cave-in at the plaza, and was surprised to find that nothing of the kind had happened. However, in the mountains to the southwest, which were under vision for a distance of twenty miles, the travel of the earthquake going west was plainly visible. On the nearer mountains great columns or pillars of dust were standing out here and there, and other columns of dust were rising over the farther hills. This made an awe-inspiring scene, accompanied, as it was, by reverberating reports like immense blasts or explosions, and for the reason that I had mistaken the dust columns for smoke columns of incipient volcanoes. These reports ceased and the shiver of the ground underfoot died away gradually, and then came an after-stillness that for the first few moments intensified the apprehension that "the worst is yet to come."

Thus ended the first and main "quake" of the series. I looked at my watch and it was 3:25, and, as I estimated that the duration of the shock was about five minutes, I set its commencement at 3:20. How those few minutes had changed the scene! The plaza and streets were deserted; the people were scattered in small groups over the hillside or huddled together in the interior patios. The women of the groups were leading in prayer. All believed the *fin del mundo* was coming on, for, as I understood afterwards, no other earthquake had occurred within the memory of the inhabitants or in their tradition. Therefore the people believed that the "crush of matter and the wreck of worlds" had been inaugurated.

This earthquake was followed by another in just five minutes, and, with appalling regularity, in intervals of five or six minutes other earthquakes followed for about two hours. The shocks continued throughout the night with a duration of from ten to thirty seconds, but with decreasing frequency. I retain the impression, however, that for the remainder of the night a fairly strong shock occurred every half hour. The frequency changed to one every two or three hours during the next day and then decreased to two or three a month for the following six months, when they practically ceased altogether, and so far as I have heard no earthquake has since occurred in that region.

The effect of the first shock was disastrous for the little town, for although the houses were low and squatty and of one-story adobe construction, the walls and roof of every house were shattered—the walls of many had fallen out and the roofs fallen in. The plaza and streets were ripped up by fissures, some as wide as six inches or more, and the irrigation ditches around the town were all broken. In about half an hour after the first earthquake the sky turned to a brownish color and the sun appeared as red as blood. The sunset that evening was gorgeous. Although there was not a cloud in the sky, every color of the rainbow was represented, with changes into wonderful combinations of blendings. This was doubtless due to the dust with which the air was laden almost to suffocation through the evening.

I found in riding over to the mine the next day that the road was crossed at various places by fissured zones in which the ground was cracked for considerable distances. Pre-existing water holes had changed to flowing springs, other water holes had dried up, and a new spring had started and was flowing copiously in the middle of the road at a point where no water had previously existed for three miles on either side. At the mine the only underground work going on was a cross-cut tunnel, which was in about 400 feet. There was no caving anywhere in this work, but the miners said the tunnel "swayed back and forth" and the rumbling and grinding noise was frightful all the while they were running out to daylight. On the surface the workmen handling the machinery ran away from the yard when "the ground commenced to sway and sink" and the material to "rock and reel over the yard."

A few days after the earthquake I had occasion to visit Moctezuma, the capital of the district, a town of some 3,000 inhabitants, situated about twenty miles south of Tepic. Here I found the houses wrecked in the same manner already described, and all the inhabitants living out of doors in shelters erected in the streets and patios. The prefect of the district had prohibited anyone from living in the houses, and this regulation lasted for six months after the first shock. The information had reached Moctezuma that the effects of the earthquake were strongly manifested among the small hamlets and villages for 100 miles south of the town. The reports from the section of the country lying east of the Cumpas or Oposura river indicated that the earth shocks were more severe in that region. A report was current that there were forty persons killed in a church in Oputo, a town thirty-five miles northeast of Tepic. At the first shocks the women and children in this town ran into the church, then the walls shattered and the roof fell in. In this neighborhood it was reported by American prospectors that a fissure two and a half feet wide was created by the shock and remained open until filled by the rains in August following.

Two weeks later I drove up to Tombstone, our outfitting point for the mine, over the road leading through Nacosari, Fronteras and by the sites of the towns now Agua Prieta and Douglas, since built. For long distances, at places, this road was fissured by wide, deep cracks, and so badly that I was obliged to make long detours, driving slowly, to get over the cracks. There were several new springs and water holes along the road, and at places the road was turned to quagmires. At Tombstone the streets were cracked and fissured, as were the walls of many of the houses. Reports stated that similar evidences of the earthquake were visible as far north as Globe and Clifton. The open fissures and the larger ground cracks left by the earthquake coursed through the country in a north and south direction, but these were joined by a network of smaller cracks. I returned to the mine by the road that went through the old San Pedro custom house and along the easterly headwater branch of the Sonora River and the town of Bacuachi. This road lies about thirty-five miles west of the Nacosari road, but it was just as badly fissured as was the Nacosari-Fronteras road.

I think it is conservative to say that the area fissured and cracked by the shocks of this earthquake covered a length of 350 miles by a width of 100 miles, or 35,000 square miles, an area approximately as large as the state of Indiana, and possibly twice this area was sensibly shocked, if not scarred, by the first earthquake.

It may be interesting to note here that in the months which followed the first earthquake I had frequent opportunities of observing the behavior of my dog during the smaller earthquakes that continued at irregular intervals during this period. The dog sensed the coming of an earthquake for some seconds before I could detect it by either sound or shake. Whether outside or inside the house, he would run and throw himself on my feet and give a low, complaining whine, then the shiver of the earthquake would become perceptible. The night following the first earthquake I slept at Tepic in an open patio, at one end of which a flock of chickens roosted. While the earthquakes, which came frequently during the night, were in progress the chickens would cluck complainingly, but after the shock was over the rooster would crow vigorously and defiantly and the roosters in the neighborhood would join in the chorus.

The five minutes or so during which the first earthquake lasted was the most selfish period of my life. Like the others, I was absolutely possessed of a feeling of "let him who can save himself."

This had been my first earthquake experience, and I have often wished since to have the experience repeated so that I might deliberately and calmly study the progress of the phenomenon. Only for a brief period of the whole experience I appreciated, if I did not enjoy, the majestic grandeur of that cataclysm; that was when I watched the dust columns rising in an advancing procession over the distant hills and heard the reverberating salvos of the earth shocks coming back from these hills, like the reports of 42 centimeters, as the earthquake was passing over the mountains to the southwest.

South Pasadena, Cal.

THE STARTING POINTS OF EARTHQUAKE VIBRATIONS

By Harry Fielding Reid

In the June and December, 1917, BULLETINS Dr. Klotz made the interesting suggestion that when an earthquake is caused by movement on a long fault, the records at different observatories may locate different points on the fault and thus indicate its length and position. A particular instance cited was the earthquake of May 1, 1915, on the margin of the Kurile Deep. The origin had been located by records from a number of stations, and later a copy of the Perth seismogram indicated, by the length of the first phase, that the origin was 500 kilometers nearer Perth than the position earlier assigned to it. This was supported by the Zi-Ka-Wei and Honolulu records. The conclusion was drawn that different stations record disturbances starting from different parts of the fault and thus make it possible to locate not only one point, but many points of the fault. This is such an interesting matter that it calls for careful analysis.

In figure 1, let O_1O_2 represent a fault; great circles at right angles to the fault would meet at two points 90° distant from every part of the fault; and the first record at stations situated near these points would come from that part of the fault where a shock, strong enough to make a record at C, first took place. If the fracture occurred simultaneously all along the fault, the beginning of a record at a station would be due to the point on the fault nearest to it. The nearest point to a station within the lune CC' would depend on the postion of the station; one end would be the nearest point of the fault to stations outside the lune.

But the simultaneous fracture along the fault is impossible. It would require the gradually accumulating stresses to reach the locally varying strength of the rock at all parts of the fault simultaneously. What must necessarily occur is this: The elastic stresses become sufficient to cause a fracture at some point; the stresses at this point are then transferred in part to neighboring points, which in turn break down; and so the fracture is propagated. Where the movement on the fault is horizontal, the stresses would apparently be transferred by compressions and rarifications; where the movements are vertical, by distortions. Under any circumstances the stresses cannot be transferred at a greater speed than that of the longitudinal elastic waves, which is therefore the greatest possible speed for the extension of the fracture; the actual speed is undoubtedly variable and probably considerably less than the maximum.[1]

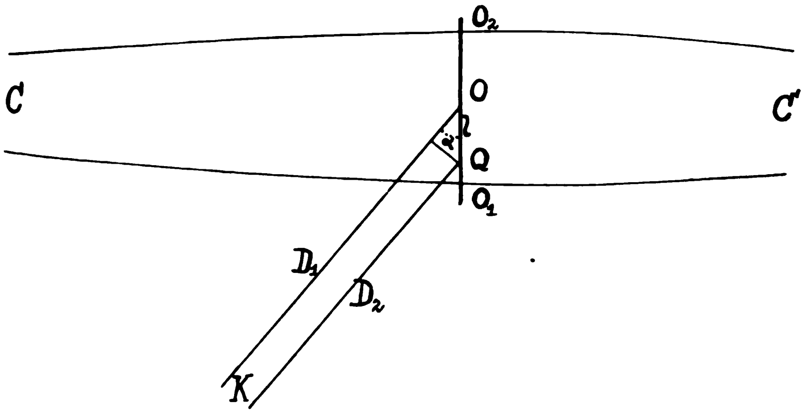


Fig. 1.

Assuming then that the fracture is extended at the maximum rate, which we may take at 7.2 kms. per second, let us see what point of the fault sends its disturbance first to a station K. Let D_1 be the distance along the great circle from the point O, where the strong disturbance commences, to the station; D_2 the distance from some other point Q of the fault. The average velocity along D_1 is slightly greater than along D_2, and distinctly greater than the speed of fracture along l; and since the path $l+D_2$ is longer than the path D_1, the disturbance will reach K along the path D_1 before it will along the path $l+D_2$. The beginning of the station's record will be due to the point on the fault where the disturbance begins; which generally would not be the point of the fault nearest to the station.

The P phase, as we have seen, is comparatively easily dealt with, because the speed of the extension of the fracture is smaller than the speed of propagation of the disturbance. But the S phase is somewhat more complicated. Let the disturbance at O be strong, and let the fracture be propagated towards O_1. Let T_1 and T_2 be the times required by the S waves to travel, respectively, from O and Q to K;

---

[1] See "Mass Movements in Tectonic Earthquakes and the Depth of the Focus"; *Beitrage zur Geophysik*, **10**, 345, 1910; or, "The Elastic Rebound Theory of Earthquakes," *University of California Publications: Geology*, **6**, 432.

we shall suppose the station sufficiently distant to permit us to consider D_1 and D_2 as parallel near the fault. Let v be the speed of extension of the fracture, whose maximum value is 7.2 kms. per second. The time for the S waves to pass directly to K will be T_1; the time for the fracture to extend to Q and the S waves, starting there, to reach K will be $l/v+T_2$. For the latter to reach K first, we must have

$$\frac{l}{v} + T_2 < T_1 \qquad (1)$$

We may replace T_2 by $T_1—\Delta T$, where $\Delta T = T_1 — T_2$; and the inequality becomes

$$\frac{l}{v} < \Delta T \qquad (2)$$

ΔT is the time necessary for the S waves to cover the distance $D_1—D_2$, or $l\cos\alpha$, where α is the angle between D_1 and the fault. If v_1 is the average surface velocity between the distances D_2 and D_1, then $\Delta T = l\cos\alpha/v_1$. We can find v_1 from the transmission curve; it is not constant, but is greater as D_1 is greater and as $D_1—D_2$ is less, as it is measured backward from time corresponding to D_1. Our inequality may now be written

$$\frac{l}{v} < \frac{l\cos\alpha}{v_1} \text{ or, } \cos\alpha > \frac{v_1}{v} \qquad (3)$$

We have seen that v_1 gets smaller as $l\cos\alpha$ becomes larger; but if the length of the fault measured from O is 4°, or 445 kms., and the station is about 36° from the fault, then v_1 will equal 7.2 kms. per second, and $\cos\alpha$ becomes unity. For all stations at a greater distance than 36° and faults not more than 445 kms. long, v_1 becomes greater than v, α becomes imaginary, and the first recorded S waves must start from O. If, as seems perfectly certain, the speed of fracture is less than 7.2 kms. per second, then the first recorded S waves will come from O for distances even less than 36°. If the speed of fracture is as small as 4 kms. per second, the lowest speed of the S waves, then O will be the starting point of the S waves for stations at all distances. This last condition is, not improbably, fairly general. The only facts I know having any bearing on the speed of propagation of the fracture are connected with the California earthquake of 1906. The fracture apparently began a little northwest of the Golden Gate; the violent shock did not take place until a half-minute later, and had its origin about 30 kms. further to the northwest.[2] These points are not accurately determined, nor do we understand the dynamics of fracturing well enough to interpret the facts with confidence; but they suggest strongly that the fracture in this case was not propagated very rapidly.

---

[2] "The California Earthquake of April 18, 1906," 2, 5-11. The Carnegie Institution, Washington, 1910.

A graphic representation of the two terms of inequality (2) shows that if the speed of fracture is sufficient to make the *S* waves start from a point on the fault nearer the station than *O*, they will start from the end of the fault and not from an intermediate point, if the station is outside the lune *CC′*; or from the nearest point to the station, if it is within the lune.

The treatment of the surface waves is like that of the *S* waves; but we do not know where they start. They must be set up by the arrival of the longitudinal or distortional waves somewhere at the earth's surface, but not necessarily at the epicenter.[3]

If a strong shock is sent out from a point very near where the fracture begins, all stations, very probably, receive their first *P* and *S* waves from this point, and not from the ends of the fault. But another procedure is possible. Suppose the fracture starts from a point where the stresses are small and the rock weak, and extends in opposite directions to places where both the stresses and rock are strong. Heavy shocks might occur at not very different times at two points many kilometers apart; and these might be the first shocks strong enough to be recorded by our instruments. The *P* and *S* waves recorded at a station would refer to the nearer of the two points mentioned. Something of this kind may have happened at the time of the Kurile earthquake; and it seems *a priori* probable that the fault ran parallel to the Kurile Deep; but the seismographic evidence does not seem sufficient to establish the fact. The record from Manila, which is nearly in the line of the probable fault, indicates an origin about 165 kms. nearer than Dr. Klotz's northern focus.[4]

Dr. Klotz's suggestion opens up many interesting questions, and, as he says, their solution depends upon the accumulation of *accurate* records. This cannot be too strongly emphasized. I believe more real information could be extracted from the records of a half-dozen stations where the time error is negligible than from many times that number where the clock error is not known.

Johns Hopkins University,
Baltimore, May 15, 1918.

---

[3] This was discussed in the Report on the California Earthquake of 1906, 2, 126.

[4] It is also to be noted, that if the fault parallels the Kurile Deep, Honolulu is nearer the northern than the southern focus and should not be used to determine the latter.

ANALYSIS OF EARTHQUAKE WAVES

By Otto Klotz

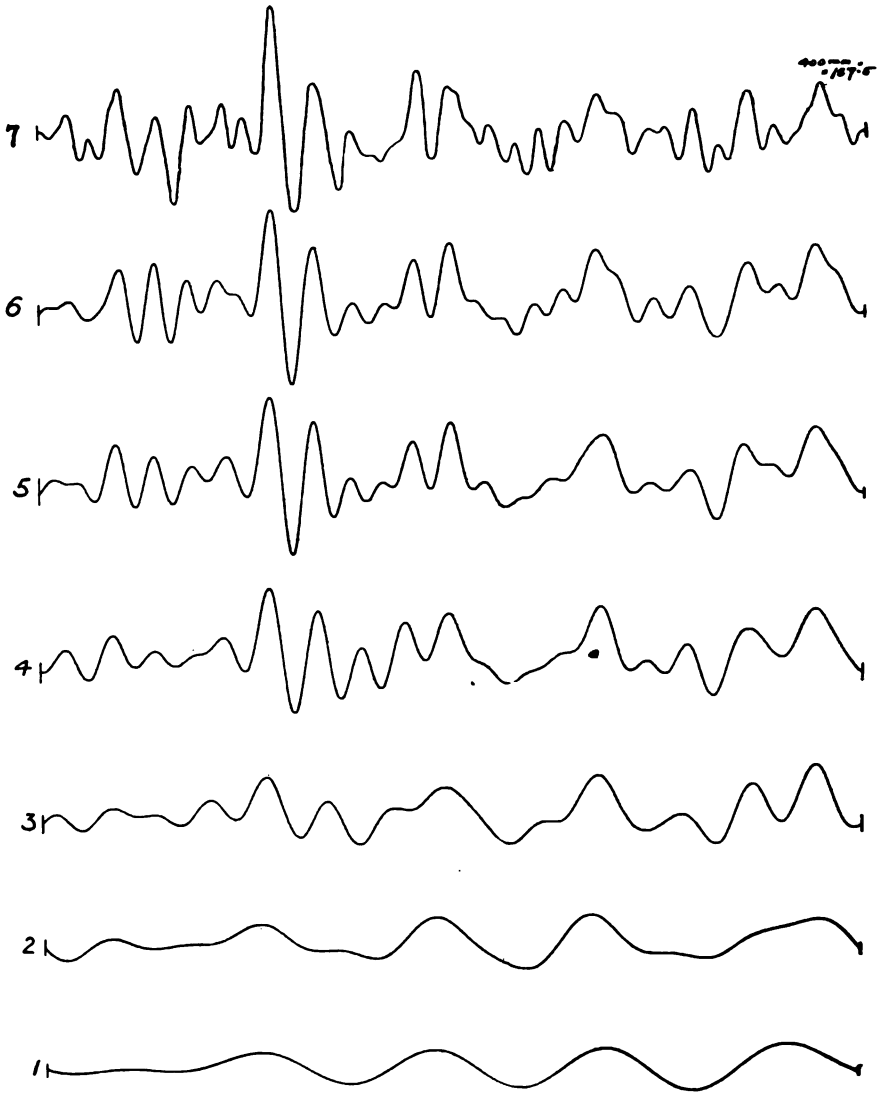
When Professor Dayton C. Miller, of the Case School of Applied Science, Cleveland, gave his splendid popular address with the marvelous illustrations of his Phonodeik on the Science of Musical Sounds, before our Royal Society at Ottawa last May, I was struck by some of the compound waves shown as resembling some of our *L* waves, and the idea of analyzing earthquake waves by means of his improved Henrici Harmonic Analyzer immediately suggested itself to me.

On the following day he gave a short talk before our section,—Mathematics and Physics,—and closed by offering to analyze any periodic curve for any member. I was not slow to accept the offer, and arranged to have the necessary material furnished. The earthquake of September 7, 1915, off the Pacific coast of Central America was selected. The analyzer and the 32-element harmonic synthesizer to which reference will subsequently be made were described by Professor Miller in the *Journal of the Franklin Institute;* the former in September, 1916, and the latter in January, 1916.

Whatever part of the seismogram is selected for analysis, that part which is chosen for a period, which it may be stated is not very easy, must be enlarged to exactly 400 mm. in order to fit the machine—the analyzer. From the seismogram of the above earthquake were chosen six sections, three from each component, N-S and E-W, viz: the beginning of *P,* which was sharp; the beginning of *S,* which was not so abrupt as *P;* and a section of *L* on which the *L* waves were obvious. The mathematical process of analysis by Fourier series is too time-consuming, as the writer found out years ago, to apply the many analyses one wants, so that one interprets or reads the periods or supposed periods directly from the seismogram, knowing at the same time that it is a questionable procedure.

The above parts chosen were enlarged photographically to the required 400 mm. and forwarded to Professor Miller to await my arrival from the eclipse expedition to Denver.

On June 13th I spent the day with Professor Miller to see and learn the modus operandi of the analyzer and synthesizer. It should



Earthquake September 6-7, 1915. *S* wave, E-W component. Ottawa. Analysis by Dayton C. Miller.

1. Synthesis of components 1 to 5.
2. Synthesis of components 1 to 10.
3. Synthesis of components 1 to 15.
4. Synthesis of components 1 to 20.
5. Synthesis of components 1 to 25.
6. Synthesis of harmonic components 1 to 30 inclusive.
7. Enlargement of original record from seismogram.

[The scale of the photograph furnished by the author was 400 mm. = 157.5 sec. This reproduction has been reduced in the ratio of 109 to 150.—Ed.]

have been stated before that the seismograms are from our two Bosch seismographs, with photographic registration; mass or bob of each horizontal pendulum 200 grammes, magnification 120.

For illustration to me of the mechanical work, the gram of the *S* waves of the E-W component, magnetically damped, was chosen. The enlarged gram covering 400 mm. represented 157^s.5.

The harmonic analyzer is adapted for thirty components, that is, the analysis of a periodic wave will show which of the simple thirty sine waves are concerned and to what degree, as shown by the amplitudes, in producing the periodic wave. The 400 mm. of the periodic wave represents some definite time interval, and it is assumed that in the next similar time interval a similar periodic wave will be produced. The thirty components represent simple sine waves whose periods are respectively the quotient of the period of the composite wave divided by the respective component; the 30th component will have a period half as long as the 15th; or a third of that of the 10th, and so on.

The analyzer takes five components at a time, so that for the thirty, six tracings or followings with the stylus of the gram of 400 mm. are necessary.

On the day of my visit Professor Miller used the components from 11 to 25, fifteen in number, and read off the sine and cosine terms on the graduated wheels, from which the amplitudes were mechanically obtained and also the phase angle; the ratio sine, cosine gave the angle, and their respective signs the quadrant. Then transferring the constants thus obtained to the synthesizer, and turning a handle—presto!—the periodic curve dependent upon those constants was produced, or drawn in ink on the blank sheet. It showed a fair resemblance to the original, and the writer saw and appreciated the great assistance the analyzer could render the seismologist, for the periods of earthquake waves are not yet satisfactorily known on any seismogram.

Professor Miller, not being satisfied with the partial analysis, examined the gram later and applied the remaining elements, 1 to 10 and 25 to 30, to the other fifteen and sent the results to Ottawa. It may be remarked that the writer considered that he had taken rather too much (in time) of the original gram to represent the *S* waves, however it served for experimental purposes.

The results of the analysis are given in the subjoined table:

Components—	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Periods of Simple Sine Waves—	$157^s.5$	78.7	51.8	39.4	31.5	26.2	22.5	19.7	17.5	15.8	14.3	13.1	12.1	11.2	$10^s.5$
Amplitudes in mm.—	1.0	1.4	2.8	5.4	6.6	1.7	2.6	0.5	0.5	2.4	1.5	5.8	1.1	2.3	3.6
Phase Angle—	102°	154°	166°	154°	286°	132°	225°	208°	214°	187°	248°	334°	293°	69°	18°

Components—	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Periods of Simple Sine Waves—	$9^s.8$	9.2	8.8	8.3	7.9	7.5	7.2	6.8	6.6	6.3	6.1	5.8	5.6	5.4	$5^s.2$
Amplitudes in mm.—	3.0	5.2	4.3	4.1	5.9	4.4	3.8	2.8	2.4	3.6	2.7	0.6	4.0	1.6	1.4
Phase Angle—	290°	198°	26°	281°	150°	110°	10°	245°	37°	282°	219°	162°	82°	342°	20°

From the amplitudes the governing simple sine waves become evident. From the above we find five marked periods standing out from their respective adjoining ones, $39^s.4$, $31^s.5$, $13^s.1$, $7^s.9$ and $5^s.6$. The amplitude of such long periods as of the first two is not obvious. The next largest amplitude is for the period of $7^s.9$, say 8 seconds, and this is a period that is not unusual to note when the period of *S* can be read at all satisfactorily. However, the most interesting fact brought out by the analysis, and one of the main reasons for communicating this brief note, is the amplitude for component 28, period $5^s.6$, which stands out boldly between its neighbors. It is the period of the pendulum at that time. In our first partial analysis comprising the components from 11 to 25, the periods between $14^s.3$ and $6^s.3$ only were covered, and hence the presence of the motion of the pendulum was not detected. When, however, the remaining components were added the hidden effect of the pendulum, which as it is magnetically damped was considered practically aperiodic, was exposed, and the lurking enemy brought to view. It will be observed that the analyzer sharply differentiated between the periods of $5^s.8$, $5^s.6$ and $5^s.4$. It would hence appear,—awaiting confirmation in further analyses,—that the analyzer is able to determine the period of the pendulum to the tenth of a second, a precision equaling that of direct observation. If true, as it appears, it is a great achievement.

Now a few words about the accompanying diagram. The unnumbered reproduction at the top is a facsimile of part of the seismogram for the *S* waves on the E-W component, magnetically damped. The beginning of the *S* waves was taken on the original as shown by the left-hand end at the short vertical line. The right-hand end was more or less arbitrary, only observing that the periodic curve might be assumed there to begin repeating itself. The numbered diagrams represent the syntheses respectively of the elements 1 to 5, 1 to 10, 1 to 15, 1 to 20, 1 to 25, and 1 to 30. When we examine No. 1, involving only five elements, and look at the harmonic analysis table, we find that the wave $31^{s}5$ is the controlling factor, yet materially affected by the adjoining one of $39^{s}4$, as is evident when we find the phase angle of the one 286° and of the other 154°, so that in the beginning their amplitudes are of opposite sign and neutralize each other, and further on are more concurrent. This may be readily illustrated by drawing two sine curves of the respective periods and amplitudes, and superposing the one on the other, making the points represented by the phase angles 286° and 154° respectively lie in the same vertical. On the diagram the two fairly uniform waves have a period of $33^{s}2$. Thus proceeding through the remaining five diagrams, each having added five elements, we come to No. 6, which includes the thirty terms of the analyzer and gives us a pretty good gram of the original seismogram. Further analyses will undoubtedly give still greater accordance. It is believed that this is the first time earthquake waves have been subjected to this method of analysis.

The amplitudes as stated are in millimeters, based on the diagram (enlarged seismogram) over which the stylus passed. Now this diagram was magnified from the original seismogram about ten times, while the theoretical magnification of the seismograph is 120, so that roughly we have 1200 as the magnification, and an amplitude of 6 mm. would in reality represent a movement of the earth particle of 6/1200 mm. or 5μ, a pretty small quantity, although representing about the largest amplitude measured.

My object in communicating this brief and imperfect note is to show the possibilities that the analyzer and synthesizer, more particularly the former, offer to the seismologist in unraveling some of the great number of facts buried in the seismogram, and of which we are still woefully ignorant. It is hoped that in the near future the writer will submit a more complete analysis, comprising the *P*, *S* and *L* waves for both components and of the same earthquake.

Dominion Astronomical Observatory,
Ottawa, July 2, 1918.

AN EXPERIMENT IN TELESEISMIC REGISTRATION

By T. A. Jaggar and Arnold Romberg

The requirements for registering teleseisms usefully are a slow-period pendulum, as little friction as possible, known constants of apparatus, a high damping ratio approaching aperiodicity, magnification so related to damping as to reproduce the relative amplitudes of various earth movements as nearly as possible proportionately, and a chronograph sheet moving fast enough to make an open record easily divisible to seconds of time.

The Omori 100-kilogram horizontal pendulum, made in Tokyo, was used, but the smoked paper and stylus were replaced by an optical system as follows: a one-ampere lamp with straight filament was set up 150 centimeters from the end of and in line with pendulum arm and somewhat higher. The tip of the arm was equipped with a magnetized steel needle protruding horizontally, and a second magnet of the same size was waxed to the center of the back of an ordinary light circular mirror 12 millimeters in diameter. This second needle stood at right angles to the mirror with its north pole close to the south pole of the arm magnet. The mirror was cemented to vertical taut silk fiber 8 centimeters long, held on a post standing on a concrete table. Horizontal displacement of the earth hence moved pendulum support and mirror support, while the frictionless magnets rotated the mirror around a vertical axis in response to inertia of the heavy mass. In case of a sharp local shock the mirror would be uninjured, as the magnets would part. The light beam was focused through and past the mirror with an anastigmat lens of approximately 30 centimeters infinity focus on a kodak film wrapped around the chronograph drum. The drum was speeded to about 32 millimeters per minute. The time-marking system was an improvised rocker actuated by an electro-magnet wired to the usual minute-contact time-piece, the rocker breaking the light circuit by lifting a copper terminal out of a mercury cup. Once a minute the light was thus extinguished, making a break in the photographically written line on the film, and once an hour a longer break was registered.

The pendulum was damped to a ratio four to one by attaching beneath the arm a perforated metal box immersed in a mixture of medium automobile oil and heavy vacuum (steam-engine) oil. The

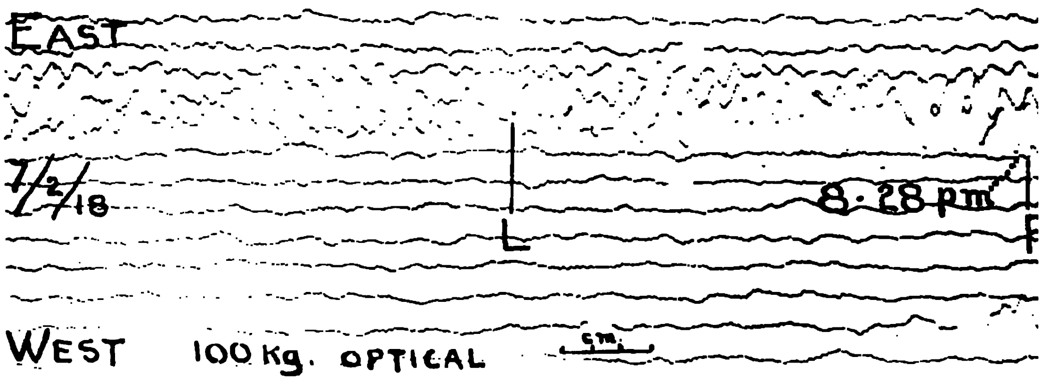


Fig. 1. Optical r

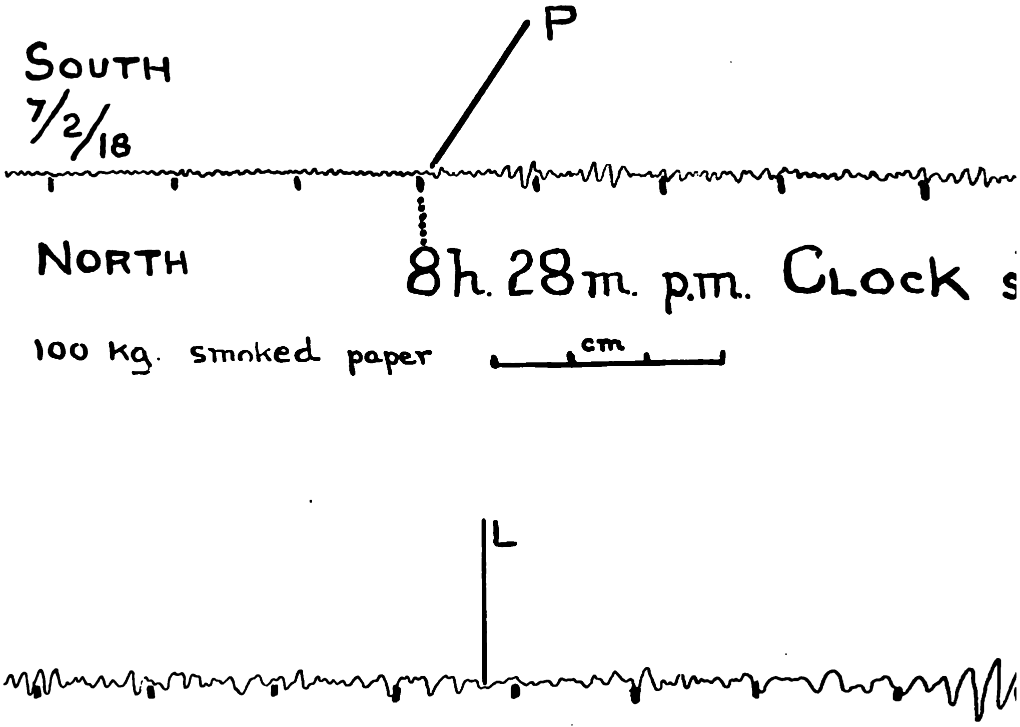
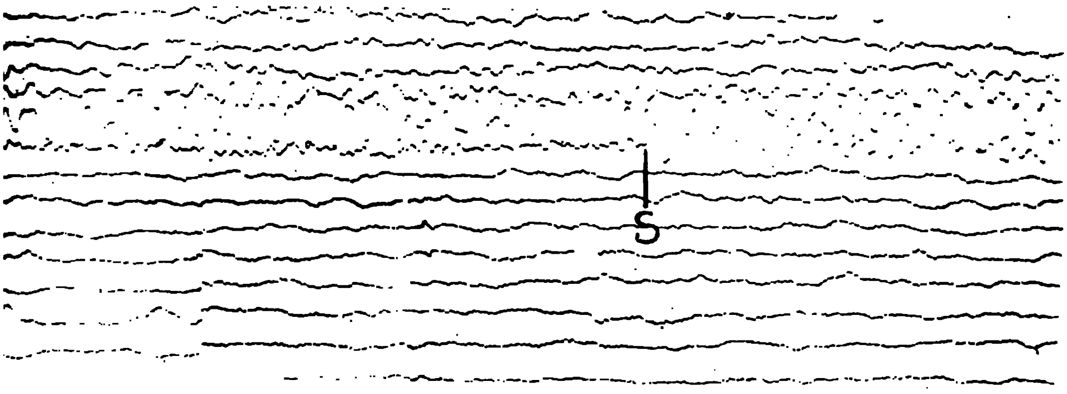
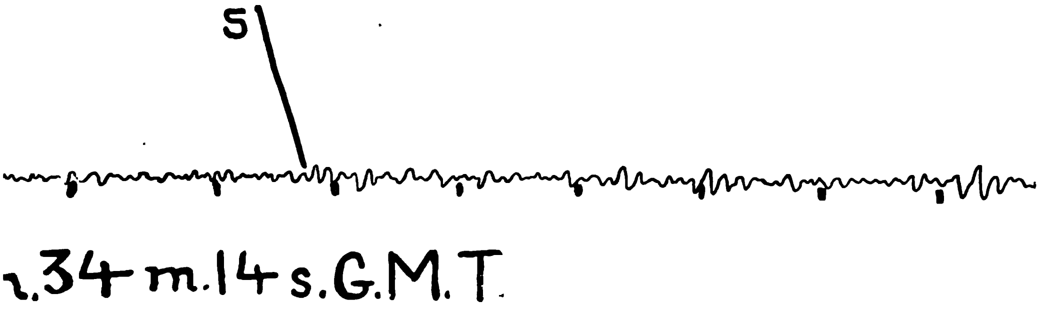
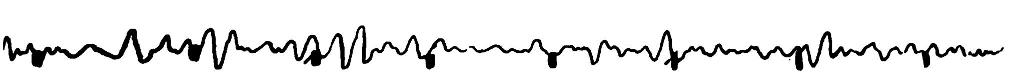


Fig. 2. T



netic transmission.





per record.

mirror was damped, to prevent any possible quick vibrations of its own, by attaching to it and beneath it, in a test-tube of medium automobile oil, a light vane of mica.

The linear magnification (V) of rapid movements of the earth was approximately 200; the period of the undamped system was approximately 14 seconds, and when damped 14.7, as shown on the two decay curves in the lower part of seismogram (Plate 15, Fig. 1), made artificially by the attendant walking around the pier. The solid friction was very small and resides in the pendulum supports. At all times the graphs indicated great sensitiveness to microseisms and to the local micro-tremor believed attributable to the Hawaiian volcanoes on which the observatory is seated. They confirmed the evidence of earlier non-optical records which indicated that this volcanic trembling is harmonic and incessant, of period approximately one-half second. This minute sinuosity of the line is lost in reproduction, but very plain on the original film.

The particular seismogram of July 2, 1918, here reproduced, shows a teleseism initiated at $8^h32^m20^s$ Hawaiian Standard Time (G. M. T. $7^h02^m20^s$ July 3d), the first (*P*) and the second (*S*) preliminary phases being exhibited with extraordinary clearness. The duration of the *P* tremors was 8^m36^s. The same earthquake was registered on smoked paper simultaneously by two Bosch-Omori 100-kilogram instruments in the same room, but with no such definition of phase. (Fig. 2, N-S component drum speed 16 millimeters per minute; magnification 100; air damping 3 to 1.) It should be noted that the times of *P*, *S* and *L* indicated on this figure are transferred from the optical seismogram for comparison.

It will be seen that the optical record is similar to the Galitzin graphs as published by Walker.[1] The Galitzin instrument, however, records galvanometrically, so depends on velocity, whereas the present instrument registers direct displacement. The Galitzin method, even though aperiodicity is used, tends to exaggeration in the long (*L*) waves, whereas it will be seen in the present seismogram the long waves, though showing some resonance with the period of the pendulum, are of very moderate proportions, and with heavier damping would probably show amplitudes still smaller. The initial movements of *P* and *S*, on which seismographic measurement of distance and direction is dependent, are sharp and unmistakable and quite similar in character to those obtained by the galvanometer method.

Hawaiian Volcano Observatory.

---

[1] "Modern Seismology," by G. W. Walker, Plates 11 and 12. Longmans, Green & Co., 1913.

SEISMOLOGICAL NOTES

The Board of Directors of the Seismological Society of America take pleasure in announcing that a grant of $250 has been received from the American Association for the Advancement of Science, to be used in the immediate investigation of earthquakes occurring in the Pacific Coast region of North America.

Southern California, March 6, 1918.—An earthquake was felt in Los Angeles and vicinity on March 6, 1918, at 10:20 a.m. This shock was also felt in Venice, Santa Monica, Culver City and Hollywood, according to press reports. As usual, this shock was reported as the result of some mysterious explosion. From meager reports received it appears that the epicenter must have been in the ocean, west of Santa Monica and Venice. At these places the intensity seems to have reached V, possibly VI. The shock was reported as far north as Van Nuys, in the San Fernando Valley, where the intensity was about IV.

In the southern portion of Los Angeles the intensity reached IV, possibly V, but was much less in the northeastern portion of the city. The shock was abrupt, of about one to two seconds duration, and some observers noticed distinct earthquake sounds.—Homer Hamlin.

Kern County, California, March 23, 1918.—An earthquake was felt at Brown and Little Lake, in Kern County, on March 23, 1918, at 7:15 a.m. It consisted of one short shock, and caused decided jarring of buildings, etc., and slight displacement of furniture. The intensity must have been V to VI. This slip evidently occurred along the eastern Sierra Nevada fault zone. It was noticed by at least five persons. Information furnished by Mr. William High, Brown, Cal.—Homer Hamlin.

Virginia, April 9, 1918.—The newspapers report an earthquake in the state of Virginia and in the District of Columbia between 8 and 9 o'clock p.m., April 9, 1918. The editors hope to be able to publish a full account of the shock in the next number of this BULLETIN.

Washington, D. C., April 10 and 20, 1918.—An earthquake was felt at Washington on April 10, 1918, shortly after 1 o'clock (G. M. T.). The seismographs of Georgetown University indicated the maximum at 1 :9 :34 and an amplitude of 1.6 mm. The intensity was III-IV in the Rossi-Forel scale. The shock was reported as felt at Lynchburg and at Richmond, Virginia. Letters were received from Woodstock, Maryland, stating that slight tremors were experienced in that region. Windows were broken in the immediate neighborhood of this observatory. On April 20th a shock was felt by people here and also by myself, and although the seismographs indicated a trace at 11 :26, it is not believed that this shock was of seismic origin.—Francis A. Tondorf, S. J., Director Georgetown Seismic Station.

Tejon Pass, Cal., April 14, 1918.—A shock was felt at Gorman and Lebec, in the Tejon Pass region, at 11 :33 a.m., April 14, 1918. It was observed by several persons. The intensity was about III of the Rossi-Forel scale.

Tejon Pass, Cal., April 17, 1918.—A slight shock was felt in the Tejon Pass region April 17th. The time has not been reported.

Eureka, Cal., April 17, 1918.—Two slight earthquake shocks were felt at Eureka, Cal., April 17th. The first was at 7 :48 a.m., lasting fifteen seconds; the second came shortly thereafter. No damage was done.

Port de France, Martinique, W. I.—Slight earthquakes were felt at Port de France, on the island of Martinique, from April 14 to April 18, 1918. Up to the 18th no damage had been done.

San Jacinto, Cal., April 21, 1918.—The earthquake at San Jacinto, Cal., April 21, 1918, is reported upon at length in special articles in this number of the BULLETIN. The intensity reached IX of the Rossi-Forel scale about San Jacinto and Hemet, where considerable damage was done. The same region suffered from an earthquake December 25, 1899. On this last mentioned shock see E. W. Claypole in *American Geologist,* Vol. 25, 106-108, Feb., 1900.

Imperial Valley, California, April 30, 1918.—On April 30, 1918, an earthquake was felt throughout southeastern California and southwestern Arizona. It occurred about 9:35 p.m., and seems to have been most severe in the Imperial Valley. At El Centro people fled from buildings, though no damage resulted. At Calexico some damage was done to a building under construction, and merchandise was thrown from shelves.

Chile, May 20, 1918.—Seismographs at St. Louis, Fordham, New York, Seattle, and Victoria, B. C., recorded a distant earthquake the forenoon of May 20, 1918. It is supposed to have been in Chile. The shocks were renewed May 23d.

Santa Fé, N. M., May 28, 1918.—A shock was felt at Santa Fé, N. M., at 5:30 a.m. It lasted about five seconds, and was strong enough to crack plaster of dwellings.

Los Angeles, Cal., July 22, 1918.—A slight shock is reported by Chas. R. Fletcher at Los Angeles, Cal., about 3:34 a.m. on July 22, 1918.

Stanford University, California, August 3, 1918.—An earthquake was felt at Stanford University, California, August 3, 1918, at 11:30:29 a.m. (Mountain time). The building rattled and the motion was distinctly felt; duration from two to three seconds. Felt by several other persons at rest. Intensity III, Rossi-Forel scale.—S. D. Townley.

REVIEWS

La Seismologia en Mexico Hasta 1917, por Manuel Munoz Lumbier. Instituto Geologico de Mexico, Boletin Num. 36.

This report covers the progress of seismological investigations in Mexico up to the year 1917. It contains an excellent summary not only of the work of the government bureaus, but of that of individuals who worked independently in the early days for the love of science.

A summary of the history of the establishment of a seismological service in Mexico was published in the *Boletin Mensual del Observatorio Meteorológico y Seismológico Central de Mexico,* No. 8, August, 1916. This publication was reviewed and summarized in the Bulletin of the Seismological Society of America, **8**, 41. A more complete statement of the work of the seismological service appears in the bulletin here under review.

In addition to the history of the work of the Mexican seismologists. the bulletin contains an excellent summary of the general principles of seismology written by Sñ. Teodoro Flores, to which is added a discussion of the seismology of Mexico, accompanied by seven seismological and tectonic maps. This discussion is perhaps one of the best brief summaries of the principles of modern seismology in existence.

The bulletin also contains an interesting chapter on the structure and its relation to the tectonic disturbances of Mexico. The country is divided into nine seismic areas and these are discussed in detail.

In addition to the general discussions, summaries of the results of the study of the more important earthquakes by various commissions and scientists are given. and these furnish seismologists the information they desire for the accurate knowledge of seismic activities in Mexico. Important discussions include: Conclusions in regard to the origin of the earthquakes of Zanatepex, September, 1902, by E. Bose; the origin of the earthquake of the 14th of April, 1907, by E. Bose and A. Villafaña and Jarcía; conclusions in regard to the earthquakes of Guadalajara, by Paul Waitz and Fernando Urbina; study of the earthquake of Acambay, by Fernando Urbina and H. Camacho.

The third part of the report consists of an excellent discussion of the construction and use of seismographs, also the interpretation of seismographic records. This section of the report also explains the coöperative work of the federal telegraphic service of Mexico, with suggestions as to the expansion of that work by coöperation with other countries.

Part IV is a valuable dissertation in regard to the construction of buildings in seismic zones. The discussion of the construction of wooden buildings is especially valuable, and interesting details of joints, struts, etc., are given. Also it would be well for anyone interested in the study of this country to read this discussion on the construction of earthquake-proof buildings of wood.

This bulletin is one of the most valuable as yet gotten out by the Geological Institute of Mexico on seismic subjects. It is a demonstration of the value of research in seismology now being carried out in the republic of Mexico.

C. F. TOLMAN, Jr.

SEISMOLOGICAL OBSERVATIONS IN OSAKA, 1916. Part II of the Annual Report of the Osaka Meteorological Observatory for 1916. Published by the Meteorological Observatory, Osaka, 1917.

This report includes lists of earthquake shocks observed by Omori horizontal pendulums, the monthly earthquake frequency, a discussion of earthquake frequency in relation to positions of origins of shocks, and notes on special earthquakes and pulsatory oscillations. It contains extremely valuable reproductions of seismographic records of important earthquakes and interpretations of these records.

C. F. TOLMAN, Jr.

SEISMOLOGICAL REPORTS RECEIVED

AMERICA

Denver, Colorado.—Jesuit Seismological Service, Sacred Heart College. Reports nos. 3 to 6, March 1 to June 30, 1918.

Harvard University, Cambridge, Mass.—Record of the Seismographic Station, from January 1 to May 31, 1918.

La Paz, Bolivia.—Boletin Sismico del Observatorio del Colegio San Calixto (P. P. Jesuitas). Reports nos. 42 to 50, October 5 to December 31, 1917.

Ottawa, Canada.—Earthquake Station, Dominion Astronomical Observatory. Reports nos. 4 to 11, March 1 to June 30, 1918.

Washington, D. C.—Seismological Bulletin of the Georgetown University, nos. 35 to 39 bis, February 1 to June 22, 1918, and compiled press dispatches for February, April, and June.

ASIA

Zi-Ka-Wei, China.—Bulletin Sismique de l'Observatoire, nos. 2 to 6, from February 4 to May 4, 1918.

EUROPE

Barcelona, Spain.—Estacion Sismica de la Real Academia de Sciencias y Artes. Reports 43 to 47, October 1, 1917, to April 30, 1918.

Coimbra, Portugal.—Boletim Sismico do Observatorio da Universidade, nos. 2 to 4 bis, February 1 to April 30, 1918.

Stonyhurst College, England.—Earthquake Records of the Observatory, from April 2, 1917, to February 25, 1918.

PHILIPPINE ISLANDS

Manila, P. I.—Seismological Bulletin of the Observatory, nos. 31 to 40, October 1 to December 31, 1917, and nos. 1 to 6, January 1 to February 28, 1918.

PUBLICATIONS RECEIVED

University of California Publications. Bulletin of the Seismographic Stations, nos. 12 to 14. The registration of earthquakes at the Berkeley station and at the Lick Observatory station, by E. F. Davis. Berkeley, 1917-1918.

Harvard Seismographic Station. Seventh Annual Report, including records. January 1-December 31, 1915. J. B. Woodworth, Cambridge, 1917.

Hawaiian Volcano Observatory. Weekly Bulletin, 4, nos. 5, 6, 7, Honolulu, 1916. No. 2, Honolulu, February, 1918.

Georgetown University Publication. Bulletin of the Seismographic Station. No. 1, pp. 1-23. The registration of earthquakes, etc., etc., from January 1, 1916, to January 1, 1917. By F. A. Tondorf, S. J. Washington, 1917. No. 2, pp. 1-30, from January 1, 1917, to January 1, 1918. Washington, 1918.

"Magnetic results, 1916." By Otto Klotz. Extract, *Journal of the Royal Astronomical Society of Canada,* July-August, 1917.

"The scientific work of the government." By Otto Klotz, Ottawa, 1917.

"Location of epicentres for 1916," by Ernest A. Hodgson. *Journal of the Royal Astronomical Society of Canada,* July-August, 1918.

"Results of observations made at the U. S. Coast and Geodetic Survey Magnetic Observatory near Tucson, Arizona, 1915 and 1916." By Daniel L. Hazard, Washington, 1918. (Earthquakes, pp. 98-100.)

"Results of observations made at the U. S. Coast and Geodetic Survey Magnetic Observatory near Honolulu, Hawaii, 1915 and 1916." By Daniel L. Hazard, Washington, 1918. (Earthquakes, pp. 96-100.)

Boletin Mensual del Observatorio Meteorologico y Sismologico Central de Mexico. Tacubaya, D. F. Enero de 1917, no. 1-Julio de 1917, no. 7.

"Informe presentado al Sr. Ministro de Instrucción Pública sobre la actividad del volcán Irazú," por J. Fidel Tristan y Ricardo Fernández Peralta. 14 pp., ill. San José de Costa Rica, 1917.

"Informe que la Comisión del Observatorio Sismogràfico presenta a la Sociedad Geográfica de Lima." 80 pp. Lima, 1908.

Republica Argentina. Oficina Meteorologica Nacional, Jorge O. Wiggin, jefe. *Boletin Mensual*, año II, nos. 2, 3, Febrero, Marzo de 1917. Buenos Aires, 1918.

"Risultati razionali ottenuti da uno studio di investigazione sismica," por Galdino Negri. La Plata, 1914.

"Sobre las constantes de Dutton y de Oldham," por Galdino Negri. *Revista del Centro Estudiantes de Ingenieria*, no. 187. Buenos Aires, 1918.

"Tiempos y velocidades en los calculos sismológicos," por Galdino Negri. *Revista del Centro Estudiantes de Ingenieria*, no. 189. Buenos Aires, 1918.

"La sismologia de los autores clasicos griegos y romanos," and "Observaciones de 1914 y 1915." Por Don Fernando de Montessus de Ballore. Boletin del Servicio Sismologico de Chile, 13. Extracto de los *Anales de la Universidad*. Santiago, 1918.

"Bibliografia general de temblores y terremotos," por F. de Montessus de Ballore. Septima Parte. Publicada por la Sociedad Chilena de Historia y Geografia. Santiago, 1917.

"Teremoto del año 1582 en Arequipa, e erupción del volcán Omate en el año de 1600." Por Fernando de Montessus de Ballore. *Revista Chilena de Historia y Geografia*, **24**, n. 28. Santiago, 1918.

"Annual Report of the Osaka Meteorological Observatory for the year 1917. Part II, seismological observations in Osaka, 1917." Osaka, 1918.

"Catalogue of Philippine Earthquakes, 1916." Reprint from the *Weather Bulletin* for December, 1916.

"Observaciones Macrosismicas del Observatorio Fabra de la Real Academia de Ciencias y Artes de Barcelona." Hojas num. 3-4 (1917).

"Ensayo de algunas formulas aplicables a los macrosismos," por el P. Manuel Mª. S. Navarro Neumann, S. J. Congreso de Valladolid. Madrid (1915).

Cronistoria dei terremoti Etiopici anteriori all' anno 1913, per L. Palazzo. *Bollettino della Società Sismologica italiana*, 19. Modena, 1915.

"Du rôle comparé des diverses nationalités dans les progrès de la sismologie moderne," par Comte de Montessus de Ballore. Est. dal *Bol. della Soc. Sis. Ital.* **20**, Modena, 1916.

"Macrosismi avvertiti in Italia nell' anno 1916." Catalogo compilato da G. Martinelli. Est. dal *Bol. della Soc. Sis. Ital.* **20**, Modena, 1916.

"A proposito del terremoto Ligure del 1887," per G. Agamennone. Risposta al F. Porro. Est. dal *Bol. della Soc. Sis. Ital.* **20**, Modena, 1916.

Il Principe B. B. Galitzin, per L. Palazzo. Est. dal *Bol. della Soc. Sis. Ital.* **20**, Modena, 1916.

Bollettino della Societa Sismologica Italiana, **20**, nos. 1, 2, 3, 4, 5, 6. Modena, 1916.

"Rettifiche e considerazioni sulla velocita del terremoto del 13 Gennaio 1915." Nota di G. Agamennone. *Rendiconti della R. Acc. dei Lincei*, **26**. Roma, 1917.

"La velocita di propigazione del terremoto Ligure del 23 Feb. 1887." *Rendiconti della R. Acc. dei Lincei*, **26**. Roma, 1917.

Bollettino Mensile della Osservazioni. Osservatorio Meteorico-Geodinamico "Guzzanti" in Mineo (Sicily). Anno **31**, nos. **11-12**. Caltagirone, 1918.

MINUTES OF THE MEETING OF THE BOARD OF DIRECTORS OF THE SEISMOLOGICAL SOCIETY OF AMERICA

MAY 4, 1918.

In the absence of the President, the meeting was called to order by Vice-President Tolman, at 2:15 p.m., at the Engineers' Club, 57 Post street, San Francisco, California. Directors Branner, Lawson, Tolman, and Townley were present.

The minutes of the meeeting of the Board of Directors of December 11, 1917, were read and approved.

The report of the Board of Election was read by the Secretary and ordered filed.

After being duly nominated, the following officers were elected for the year:

President	C. F. MARVIN
First Vice-President	C. F. TOLMAN, JR.
Second Vice-President	OTTO KLOTZ
Third Vice-President	H. O. WOOD
Secretary-Treasurer	S. D. TOWNLEY

The report of the Secretary-Treasurer for the year ending April 6, 1918, was read and ordered filed.

The report of the Auditing Committee was read by the Secretary and ordered filed.

The actions recorded below were taken by the Board:

(a) The following named persons were elected to membership in the Society: F. W. Bunyan, Sacramento, Cal.; Wendall P. Hoge, Mt. Wilson, Cal.; Handforth Hope-Jones, Lima, Peru; G. F. Marsh, Lone Pine, Inyo County, Cal.

(b) The following named institutions were placed on the list of subscribers to the BULLETIN: Indiana University Library, Bloomington, Ind.; Iowa State College, Ames, Iowa; the Director of Meteorological Service, Dept. of Marine and Fisheries, Toronto, Ontario, Can.; Mount Wilson Solar Observatory, Solar Observatory Office, Pasadena, California; University of British Columbia Library, Vancouver, B. C.

(c) The Secretary reported the resignation of George C. Branner, W. S. Franklin, C. W. Henderson, W. H. Hobbs, E. M. Keyser, B. C. Ledyard, H. L. Middleton, Oakland Free Library, F. B. Peck, George O. Smith and George O. Spencer; the death of A. H. Purdue and D. G. Scofield; and the dropping of fourteen members for the non-payment of dues.

(d) The Secretary reported that a grant of $250, for the year 1918, had been made to the Society by the Committee on Grants of the American Association for the Advancement of Science, for the investigation of earthquakes. The grant was accepted by the Board, and the Secretary instructed to write a letter of appreciation to the Chairman of the Committee.

(e) It was decided to use the grant of $250 for a thorough investigation and mapping of the San Jacinto fault, provided it is possible to find the right man for the work.

(f) The sum of $100 was appropriated from the General Fund to cover the expense of the investigations of the San Jacinto earthquake of April 21, 1918, carried out by Homer Hamlin and S. D. Townley.

(g) The salary of the Secretary-Treasurer was continued at the rate of $20 per month for the fiscal year 1918-19.

Adjourned 3:45 p.m.

S. D. Townley, *Secretary.*

REPORT OF THE BOARD OF ELECTION OF THE SEISMOLOGICAL SOCIETY OF AMERICA

San Francisco, Cal., April 6, 1918.

President and Members of the Seismological Society:

We, the undersigned judges of election, certify that 108 ballots were cast at the annual election, held in San Francisco on this date, with the following result:

Bernard Benfield	33	J. K. Moffitt	41
J. C. Branner	106	A. H. Palmer	41
W. W. Campbell	97	H. F. Reid	82
E. F. Davis	38	R. W. Sayles	56
R. S. Holway	44	C. F. Tolman, Jr.	89
Otto Klotz	63	S. D. Townley	103
A. C. Lawson	94	B. M. Varney	22
A. G. McAdie	83	H. O. Wood	80
C. F. Marvin	89	J. B. Woodworth	85

The following named, being the twelve receiving the highest number of votes, are declared elected directors of the Society for the year 1918-19:

J. C. Branner
S. D. Townley
W. W. Campbell
A. C. Lawson
C. F. Marvin
C. F. Tolman, Jr.

J. B. Woodworth
A. G. McAdie
H. F. Reid
H. O. Wood
Otto Klotz
R. W. Sayles

R. S. Holway,
Frank V. Cornish,
Bernard Benfield,
D. S. Richardson,
Board of Election.

REPORT OF SECRETARY-TREASURER

From April 7, 1917, to April 6, 1918.

The total number of members of the Society and subscribers to the BULLETIN is now 408, exactly the same as at the time of my last report a year ago. Five members were lost through death: Richard E. Call, New York, N. Y.; John T. Fogarty, San Francisco, Cal.; George W. Riter, Salt Lake City, Utah; R. H. Loughridge, Berkeley, Cal.; A. H. Purdue, Nashville, Tennessee.

The Santa Barbara Channel earthquakes of April, 1917, were investigated by the Society and the report published in the June number of the BULLETIN. This work was made possible through a generous gift from Dr. J. C. Branner.

Volume 7 of the BULLETIN, containing 163 pages and twelve plates, was issued during the year 1917.

The financial report is as follows:

Dr. GENERAL FUND	
To balance, April 7, 1917	$ 102.33
Dues and subscriptions	790.73
Reprints	13.70
Sale of publications	36.00
Gifts from J. C. Branner	70.65
Transfer from Sayles Fund, interest	235.00
Transfer from Life Membership Fund, interest	21.60
Total	$1,270.01
Cr.	
By Stanford University Press, printing Vol. 7, Nos. 1 and 2	$ 288.10
Stanford University Press, reprints	28.70
Stanford University Press, miscellaneous printing	1.50
Stanford University Press, manila envelopes	8.00
Times Publishing Co., printing Vol. 7, Nos. 3 and 4	230.05
Times Publishing Co., reprints	13.90
Times Publishing Co., manila envelopes	9.50
Leland Stanford Junior University, miscellaneous printing	6.25
Commercial Art Co., illustrations	42.15
Second class postage on BULLETINS	4.66
Foreign postage on BULLETINS	8.07
Stamped envelopes	21.60
A. C. Mattei, investigation of Santa Barbara Channel Earthquakes	67.65
Miscellaneous postage	13.50
Express	1.20
Rent safety deposit box	2.00
W. F. Loel, drawings	3.00
J. L. Vincenz, drawings	3.00
S. D. Townley, salary Secretary-Treasurer	240.00
Balance, April 6, 1918	277.18
Total	$1,270.01

LIFE MEMBERSHIP FUND

Dr.	
To balance, April 7, 1917	$ 525.00
Three life memberships	75.00
Interest from Berkeley Bank of Savings and Trust Co.	21.60
Total	$ 621.60
Cr.	
By interest, transferred to General Fund	$ 21.60
Balance, April 6, 1918	600.00
Total	$ 621.60

SAYLES FUND

Dr.	
To balance, April 7, 1917	$4,000.00
Interest from Mutual Building and Loan Association of San Jose and College Park	55.00
Interest from Palo Alto Mutual Building and Loan Association	120.00
Interest from Truckee Lumber Co.	60.00
Total	$4,235.00
Cr.	
By transfer to General Fund, interest	$ 235.00
Balance, April 6, 1918	4,000.00
Total	$4,235.00

S. D. TOWNLEY,
Secretary-Treasurer.

REPORT OF THE AUDITING COMMITTEE

The books of the Seismological Society of America were submitted to the Auditing Committee of the Society by Secretary-Treasurer Townley, on the 3d day of May, 1918, the period to be audited being from April 7, 1917, to April 6, 1918.

1. All expenditures were substantiated by properly receipted bills.
2. Membership cards, showing dues received during the year, were found to be properly credited in the General Fund.
3. All book entries were checked and found to be correct.

The balances in the various accounts on the 6th day of April, 1918, were as follows:

General Fund	$ 277.18
Life Membership Fund	600.00
Sayles Fund	4,000.00
Total	$4,877.18

Attention is called to the fact that the stock certificates of the Mutual Building and Loan Association of San Jose, Palo Alto Mutual Building and Loan Association, and the bond of the Truckee Lumber Company were not submitted to the Auditing Committee.

Otto von Geldern,
J. K. Moffitt,
Auditing Committee.

ROSSI-FOREL SCALE OF EARTHQUAKE INTENSITIES

I. **Microseismic shock:** recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds; the shock felt by an experienced observer.

II. **Extremely feeble shock:** recorded by several seismographs of different kinds; felt by a small number of persons at rest.

III. **Very feeble shock:** felt by several persons at rest; strong enough for the direction or duration to be appreciable.

IV. **Feeble shock:** felt by persons in motion; disturbances of movable objects, doors, windows; creaking of ceilings.

V. **Shock of moderate intensity:** felt generally by everyone; disturbance of furniture, beds, etc., ringing of swinging bells.

VI. **Fairly strong shock:** general awakening of those asleep; general ringing of house bells; oscillation of chandeliers; stopping of pendulum clocks; visible agitation of trees and shrubs; some startled persons leave their dwellings.

VII. **Strong shock:** overthrow of movable objects; fall of plaster; ringing of church bells; general panic, without damage to buildings.

VIII. **Very Strong shock:** fall of chimneys, cracks in walls of buildings.

IX. **Extremely Strong shock:** partial or total destruction of some buildings.

X. **Shock of extreme intensity:** great disaster, buildings ruined, disturbance of the strata, fissures in the ground, rock-falls from mountains.

The Bulletin of the Seismological Society of America

VOL. VIII DECEMBER, 1918 No. 4

THE VIRGINIA EARTHQUAKE OF APRIL 9, 1918.[1]

By THOMAS L. WATSON

In the evening of April 9, 1918, middle and northern Virginia were feebly, though sensibly, shaken by an earthquake that was felt in the District of Columbia, over parts of West Virginia and Maryland, and in at least one locality in Pennsylvania. Reports indicate that the earthquake was general throughout the Shenandoah Valley in Virginia and northward through the Cumberland Valley in Maryland. Records were obtained on the seismographs at Washington, D. C. (intensity III-IV of the Rossi-Forel scale), and the shock was of sufficient intensity to be registered by the instruments at Cornell University, Ithaca, N. Y., and at Harvard University, Cambridge, Mass.[2]

It is not possible from the meager data to make an accurate estimate of the total area over which the shock was felt, but it was probably not less than sixteen thousand square miles in Virginia. The extreme points from which reports were received are Colebrook, Berks County, Pa., about sixty miles northwest of Philadelphia, on the north; Danville, Va., about four miles north of the Carolina boundary, on the south; Williamsburg, Va., forty-eight miles east of Richmond, and Solomons, Md., near the confluence of Patuxent River with Chesapeake Bay, seventy-five miles north of Williamsburg, Va., and sixty miles southeast of Washington, D. C., on the east; Roanoke City, in the Valley of Virginia, on the southwest; and Buckhannon, Upshur County, W. Va., in the Appalachian Plateau, on the west.

---

[1] The information regarding the earthquake was obtained from various sources, but chiefly from questionnaires sent out by the writer shortly after the occurrence of the shock, from newspaper accounts, and from Dr. W. J. Humphreys of the U. S. Weather Bureau, Washington, D. C., who generously furnished data reported by the Bureau's many coöperative observers.

[2] In a personal communication to the writer Professor Woodworth states that the Harvard record was very poor.

Excluding the Appalachian Valley Ridges and the Appalachian Plateau to the west, the shock was felt in each of the physiographic provinces of Virginia and Maryland, including in Virginia the western part of the coastal plain as far south as Richmond and east to Williamsburg, the entire length of the Piedmont Plateau from the Potomac to Danville on the south; over the northern and middle Blue Ridge; and the great valley as far southwest as the city of Roanoke. (See map, Plate I.) A report from Buckhannon, Upshur County, W. Va. (intensity II R.-F. scale), indicates that the shock was felt in the Appalachian Plateau province west of the valley ridges.

Over most of the region the shock was slight—very feeble to feeble in intensity (II to IV of the Rossi-Forel scale). In the northern Shenandoah Valley region of Virginia and northward for a short distance into West Virginia and Maryland, where the intensity was greatest, the shock was of moderate (V) to fairly strong (VI) intensity. It was the severest shock felt in the Shenandoah Valley since the Charleston earthquake of August 31, 1886, and it exceeded the latter in intensity at several places. Practically no damage was done, but the people in many places over the northern valley region were greatly alarmed and some were so badly frightened that they rushed from their houses. One account states that "consternation in some quarters assumed almost a panic, women faiting, . . . etc." Most of the reports agree that houses were shaken more or less violently, and loose objects, such as dishes and windows, etc., rattled, accompanied in many places by loud noises.

The time of the shock recorded at the Georgetown University Seismological Observatory, West Washington, D. C., was $1^h\ 9^m\ 12^s$ Greenwich Mean Time. Naturally the non-instrumental reports as to the time of the shock differ considerably, the best estimate being between 9:09 and 9:10 p.m. (Eastern Time), which is in agreement with the writer's observation in his home at the University of Virginia, where the shock was distinctly felt.

Newspaper accounts published the next morning, April 10, 1918, and subsequent reports gathered by the writer over most of the affected region, indicate that only slight actual damage resulted, confined chiefly to the Shenandoah Valley region, where the intensity was highest. The glass in windows of houses was broken and in several localities the plaster of the ceilings in residences was badly cracked. A report from Clear Spring, Washington County, Md., to the

Weather Bureau, reported five panes of glass broken. Director Tondorf reports that windows were broken in the Georgetown Hospital, which is about three hundred yards distant from the seismological observatory. This is the only point beyond the limits of the great valley from which even the slightest damage was reported as a result of the shock.

The *Page News and Courier,* of May 31, 1918, published at Luray, Page County, Va., states that the earthquake opened a strong spring near Hamburg. Since that time a strong spring has been bubbling up almost in the middle of the road. The water is cold and very clear and strongly impregnated with calcium carbonate derived from limestone, the principal rock in that locality. The present spring has all the appearance of being unfailing. Special inquiry by the writer failed to indicate any surface modification in any part of the affected region, such as opening of fissures or cracks, stream changes, etc. Newspaper accounts mentioned the falling of trees in two localities, but in each case the destruction was due undoubtedly to the strong winds prevailing at the time and not to the earthquake.

From a total of fifty-two reports received from Virginia, thirty-nine reported one shock, nine reported two shocks, and two reported three shocks. In the Shenandoah Valley province two shocks were reported at Berryville, Dale Enterprise, Front Royal, Luray, Harrisonburg, and Staunton; and in the Piedmont Plateau, at Gordonsville, New Canton, and Rapidan. At Luray and Winchester the first shock occurred about 9:10 p.m., April 9, 1918, and the second about 2 a.m., April 10, 1918. Several reports received from Winchester indicated that the second shock was equal in intensity to the first. At Harrisonburg, Dale Enterprise, and Staunton the two shocks were separated by an interval of only a few minutes. At Highland Park, a suburb of Richmond, and at Culpeper, near the western margin of the Piedmont Plateau, three distinct shocks were reported. Under date of April 16, 1918, the Luray paper published the statement that northern Virginia was visited again on that date by another earthquake at 8:40 a.m., the fifth within a week at Luray.

The duration of the shock recorded at the Georgetown University Seismological Observatory was $4^m\ 16^s$. The period may possibly have been shorter, since Director Tondorf stated that the end was not quite certain because of being lost in heavy wind markings. There was necessarily considerable variation in the observational reports as to the duration of the shock, the range being from one second to five minutes. The best average, estimated by the writer from a study of the reports received, gives a probable duration of thirty to forty-five seconds.

About 45 per cent of the observers report having heard a noise or sound which either preceded or accompanied the shock. The sound or noise was variously described as "rumbling," "a hoarse rumbling," "like distant or low thunder," "running of a heavy motor truck with exhaust open," "an auto with the cutout open," "running of a heavy railroad train," "a train running beneath the house at some depth," "a heavy or violent wind," "a giant explosion," "a loud explosion," etc. A study of the reports discloses the fact that the places at which a sound was heard were not confined to any particular part of the region affected by the shock, but were heard in the Shenandoah Valley, the northern Blue Ridge, the Piedmont Plateau, and the Fall Belt. However, much the largest number of places at which sounds were heard was located within the Shenandoah Valley region and was nearly double the total number of places over the rest of the affected region.

The non-instrumental or observational data are summarized in Table I, with the columns of duration, sounds, and observer purposely omitted.

Plate 16 is a physiographic map of a part of Virginia on which is marked the intensity of the shock at each of the more important places from which reports were received. The observational or non-instrumental data are given in Table I. No attempt has been made at drawing isoseismals on the map because of the incompleteness of data. Attention is directed, however, to the fact that not a single report was received by the writer of the earthquake having been felt in the Valley Ridges subprovince of folded Paleozoic sedimentary rocks immediately west of the Shenandoah Valley subprovince, the region of highest intensity. On the other hand, the shock was distinctly felt (highest intensity IV-V, R.-F. scale) over the region of crystalline rocks (including the Blue Ridge and Piedmont Plateau) on the east side of the Shenandoah Valley, and still farther east over parts of the coastal plain (intensity I-IV, R.-F. scale). More complete investigation would undoubtedly discover persons in the Valley Ridges subprovince who felt the shock, since it was reported felt at Buckhannon, Upshur County, W. Va., (II, R.-F. scale), which town is located some distance west of the valley ridges subprovince well within the Appalachian Plateau of nearly flat-lying sedimentary rocks.

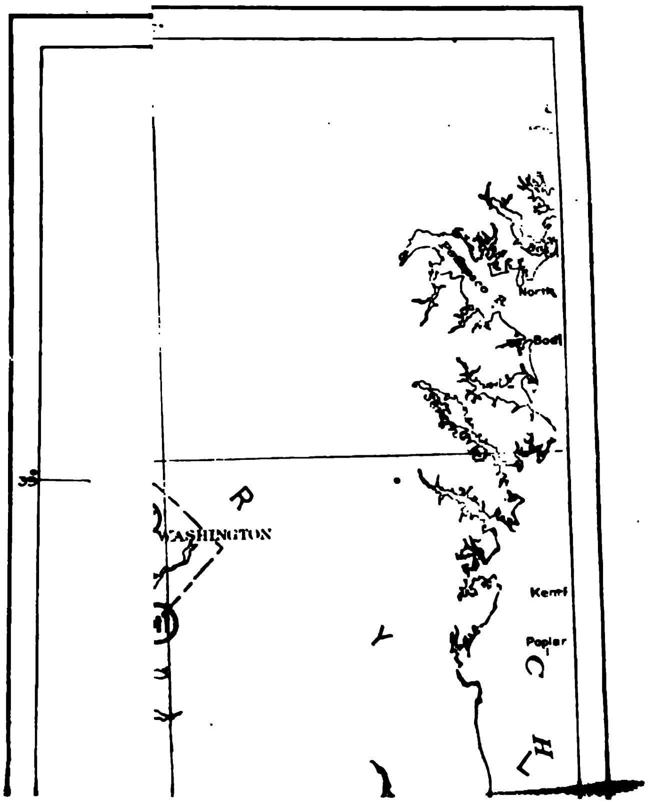

35
R
WASHINGTON
North
Bodl
Y
Kent
Poplar
C
H
L

TABLE I. NON-INSTRUMENTAL EARTHQUAKE REPORTS, 1918.

Station.	Approximate N. Latitude.	Approximate W. Longitude.	Intensity R.-F. Scale.	No. of Shocks.	Remarks.
DISTRICT OF COLUMBIA					
Washington	38°54′	77°03′	3	1	Gradual trembling. Windows were broken in Georgetown University Hospital.
MARYLAND					
Bagley	39 30	76 23	1	1	Gradual trembling.
Baltimore	39 17	76 37	2	1	
Chewsville	39 30	77 37	4	1	Gradual trembling S.W.-N.E.; like blasting.
Clear Spring?.....	39 37	77 55	..	..	Five panes of glass found broken.
College Park......	38 58	76 55	3	1	
Solomons?	38 19	76 27	4?	1?	Abrupt trembling with slight rumbling.
Takoma Park	38 58	77 01	3	1	
Woodstock	39 19	76 55	2	1	Gradual trembling.
PENNSYLVANIA					
Colebrook	40 26	76 04	2	1	Gradual trembling.
VIRGINIA					
Alexandria	38 48	77 03	3	1	Rain accompanied by high winds lessened the effects of the shock. Country for miles around was shaken for more than 3 minutes.
Arvonia	37 41	78 21	3	1	Abrupt trembling.
Berryville	39 09	77 59	5	2	Sounded like an auto with the cutout open.
Brookneal	37 05	78 55	2	1	Slight shock; felt by only a few people.
Buchanan	37 32	79 41	1	1	Gradual trembling.
Castleman's Ferry	39 07	77 59	3-4	1	Sounded like low thunder.
Charlottesville ..	38 02	78 28	3	1	Abrupt trembling; rumbling like low thunder.
Chatham	36 45	79 26	1	1	
Columbia	37 45	78 13	3	1	Sounded like a violent wind.
Culpeper	38 29	77 59	4	3	Abrupt rocking.
Dale Enterprise..	38 27	78 55	3	2	Abrupt trembling; rumbling.
Danville	36 34	79 26	2	1	Gradual rocking.
Edinburg	38 49	78 34	6	1	Rumbling noise that increased the fear of many. Ceilings in houses were badly cracked.
Farmville	37 18	78 24	3	1	Very distinct. Houses were shaken and windows rattled.
Fredericksburg	38 18	77 28	3	1	Rumbling sound.
Front Royal........	38 55	78 11	4	2	Noise likened to a loud explosion.

TABLE I.—*Continued.*

Station.	Approximate N. Latitude.	Approximate W. Longitude.	Intensity R.-F. Scale.	No. of Shocks.	Remarks.
Gordonsville	33°18′	78°11′	3	2	Rapid trembling.
Guinea	38 09	77 26	1	1	Gradual trembling W.-E.
Harrisonburg	38 25	78 52	5	2	A hoarse rumbling noise. S. to N. and N.E. Glass in windows broken.
Highland Park	37 34	77 25	3	3	Houses severely shaken for several seconds.
Lantz Mills	38 51	78 36	5	1	Rumbling most uncanny. Chandeliers swung like pendulums.
Leesburg	39 07	77 34	4	1	No appreciable noise.
Lexington	37 48	79 26	3	1	Rumbling sufficient to cause children to ask what it was.
Louisa	38 02	78 00	4	1	Noise like tin being torn from the roof of a house. One or two people awakened from sleep.
Luray	38 41	78 27	5	2	Likened to a giant explosion. Felt throughout Page County.
Lynchburg	37 25	79 09	2	1	Gradual trembling. Shock felt in the contiguous counties.
Madison C. H.	38 23	78 15	4	1	Distinct rumbling noise from the N.W.
Manassas	38 45	77 28	3	1	Abrupt trembling.
Mineral	38 01	77 54	3	1	Noise similar to distant thunder. N.E.
New Canton	37 43	78 18	4	2	Abrupt trembling.
New Market	38 39	78 40	4	1	Rumbling noise like thunder.
Orange	38 15	78 07	4	1	Abrupt rocking, rumbling.
Palmyra	37 52	78 16	3	1	
Purcellville	39 08	77 43	4	1	No appreciable noise.
Rapidan	38 19	78 04	3	2	Gradual trembling.
Richmond	37 32	77 26	3	1	Gradual rocking N.W.-S.E.
Riverton	38 57	78 11	4	1	
Roanoke	37 16	79 56	2	1	Gradual rocking.
Stafford	38 26	77 24	3–4	1	No appreciable noise.
Staunton	38 10	79 04	4	2	Gradual trembling N.E. S., rumbling. Glass in some windows broken. Surrounding country violently shaken.
Tenth Legion	38 35	78 43	4	1	Rumbling noise like thunder.
Timberville	....	....	4	1	Rumbling noise like thunder.
Top of Blue Ridge (E. of Castleman's Ferry)	39 07	77 50	4	1	Sounded like a heavy wind.
Trevilians	38 03	78 03	4	1	Noise similar to "a train running beneath the house at some depth."

TABLE I.—*Concluded.*

Station.	Approximate N. Latitude	Approximate W. Longitude	Intensity R.-F. Scale	No. of Shocks	Remarks.
University	38°02′	78°31′	3	1	Abrupt trembling S.W.-N.E.; rumbling like heavy thunder.
Warrenton	38 43	77 48	3	1	Distinctly felt and heard; caused but little alarm and no damage.
White Post	39 04	78 07	4	1	
Williamsburg	37 16	76 42	2	1	
Winchester	39 10	78 10	5	1	Abrupt trembling, rumbling like running of heavy motor truck with the exhaust open. Plaster in houses cracked. Similarly felt throughout Frederick County.
Woodbury Forest (School)..	38 17	78 08	3	1	No noise.
Woodstock	38 53	78 31	5	1	Gradual trembling E.-W., rumbling like running of a heavy railroad train.
WEST VIRGINIA					
Buckhannon	38 59	80 15	2	1	Gradual trembling.
Martinsburg	39 28	77 58	5	1	Gradual bumping, rumbling.

NEWSPAPER ACCOUNTS FROM THE SHENANDOAH VALLEY, VIRGINIA

Most of the newspapers published within the limits of the region affected by the shock carried prompt but in most cases very brief accounts of the earthquake. In the valley region, where the shock was the severest, the newspaper accounts were more complete and instructive. This was especially true of the account published by the *Winchester Evening Star*. Descriptions published in several of the valley papers are given below:

Winchester.—The *Winchester Evening Star* of April 10, 1918, carried a very full statement of the occurrence of the earthquake in that locality on the evening of April 9. The statements which follow below are quoted from the account published in the above paper:

> Winchester experienced last night its first real earthquake shock, which occurred at 9:10 o'clock during a howling blizzard which was raging. . . . In this city the experiences of citizens were very much the same. The shock resembled the effect produced by the vibration of heavy machinery, while the rumbling was of the volume of a heavy motor truck running with the exhaust

open. In many homes the inmates rushed into the blizzard which was raging at the time and great excitement prevailed everywhere.

Some hundreds of calls began going over the phone from inquirers asking the cause of what appeared to be a long continuous explosion. The quake lasted only about twenty seconds, but it seemed to many persons to be about that many minutes.

A series of unusual occurrences locally were coincident with the earthquake shock. Shortly after the quake all of the electric lights in Winchester went out and the city was in total darkness until daylight. The town clock stopped during the night, and the darkness, with the wind howling and a blizzard prevailing with six inches of snow falling, with a severe earthquake, all served to spread terror in many minds.[3]

When the shock took place at 9:10 o'clock very few people had retired for the night. The shock began with a loud rumbling which caused even the largest brick buildings in the city to tremble as though some heavy machinery had been installed and was running at high speed with great vibration. At the same time the noise exactly resembled the efforts of some motor truck to extricate itself from a stalled position, the loud rumbling seeming to be located in the houses and the volume of sound being about equal to a large automobile running with its exhaust open.

The shock and noise continued for perhaps fifteen seconds, and then dying down was succeeded by sharp explosions, and then the sound grew gradually fainter until at the end of twenty seconds' time—which seemed, however, to the terror-stricken people like an age—the houses ceased to rock, the murmurings of the earth died away, and people began to gather their wits and seek the cause, and, in some instances, to seek safety in flight from their homes.

The experiences of hundreds were alike in every detail, the comparison of the automobile exhaust being used by many to illustrate the sensation of the quake.

Those persons who have furnaces in their homes rushed to their cellars to see if the boilers had exploded. Others thought their water pipes had burst, while many others thought the noise and the rocking of houses was due to the series of blasts from faraway rock quarries.

Many people ran from their homes and sought refuge in the homes of neighbors, glad of the comfort which companionship afforded. Many others, terror-stricken at their experiences, refused to go to bed again, but sat up throughout the night.

Later on those who sat up were denied even the comfort which light afforded them, because the entire electric light system ceased to function about midnight and the city was in darkness until daylight.

---

[3] Neither the failure of the electric lights nor the stopping of the town clock around midnight could be attributed to the earthquake, since the first and principal shock occurred nearly three hours earlier and the reported second shock at least an hour later than the time of failure of the lights and clock.—T. L. W.

From some unexplained cause the big town clock on top of the city hall stopped some time after midnight, but it is not thought that this had anything in common with the earthquake.

Little details of how far-reaching the earthquake was could be obtained today, because of the fact that the telegraph wires were all down in many directions, particularly those wires coming into Winchester. It was learned, however, that while the quake was widespread throughout the east, little actual damage resulted.

In Winchester the plaster on walls was cracked, lighted lamps were rocked and nearly upset by the vibrations, while dishes were rattled and every house was rocked on its foundations as though it had been seized by some giant hand and shaken like a dog shakes a rat.

Last night's shock was the most violent ever experienced in this section, and coming as it did, during the prevalence of an unusually severe wind and snow storm, it caused alarm and terror in almost every breast.

Out in Frederick County the experiences were the same as in town. Many people called up Winchester to learn the cause of the shock and also called up neighbors on the phone to learn if the latter had also had a like experience. The loud noise seemed to be coming from every room in the house, but a search could not disclose the source. At the moment few persons had thought they were passing through a severe earthquake shock, and all seemed bent on locating some reasonable theory for the thing, but when none could be found, then terror for the first time seemed to seize them.

Many alarming reports as to damage done in this section have been received by The Star today. For instance, it was stated that the quake had opened up huge chasms in the mountains of Warren County, causing the earth to roll down on the Norfolk & Western Railroad tracks, blocking traffic.[4]

An investigation disclosed that last night the high wind blew a large tree across the tracks, stopping several trains until the tree could be removed.

Many people in Winchester today declare that a second earthquake shock occurred at 2 o'clock this morning which equaled in intensity the first shock at 9:10 last night.

Luray.—The *Page News and Courier* of April 12, 1918, published at Luray, carried the following description of the earthquake on the evening of April 9:

The severest earthquake shock ever felt in this latitude was felt all over Page County Tuesday night at 9 o'clock. On account of the heavy snow falling at the time nearly everybody was indoors, which intensified the fear of all who felt the quake. In some parts of Luray the shock is said to have been so severe as to knock people from their chairs. Many people were badly frightened, some of them being restrained from jumping from upstairs windows. For some time it did not dawn on our people what the trouble was, some thinking it was a giant explosion. Houses swayed and windows rattled and consternation in some quarters assumed almost a panic, women fainting and having to be revived by artificial means.

---

[4] As stated elsewhere in this paper the writer, upon careful inquiry, was unable to obtain any evidence that the earthquake opened chasms in Warren County or in any other part of the affected region, or that it caused earthslides.—T. L. W.

The night, a sleepless one to many, saw another shock between 2 and 3 o'clock on Wednesday morning. This was of short duration, though the shock was of sufficient force to be unmistaken. All in all, the night will be handed down to succeeding generations as a very eventful one in the history of the Valley of Virginia.

Under date of April 16, 1918, the same paper reported that northern Virginia was visited again on that date by another earthquake shock at 8:40 a.m., the fifth within a week at Luray, when people indoors ran to the streets. The statement adds that buildings rocked and windows rattled.

Harrisonburg.—The *Daily Independent* of April 10, 1918, of Harrisonburg, carried the following account of the earthquake on Tuesday evening:

For the first time in her history Harrisonburg and the Shenandoah Valley last night at exactly 9:08 o'clock experienced a distinct earthquake shock.

In Harrisonburg the shock was felt when a hoarse rumbling was heard as if coming from the very depths of the earth. Apparently the tremor was from south to the north and northeast. Buildings were shaken and windows were caused to rattle violently. Timid people were frightened and several telephone calls were answered by the Daily Independent last night from persons who wished to know what had happened.

WEATHER CONDITIONS

Especial attention is directed to the weather conditions at the time of occurrence of the earthquake on account of prevalent winds of high velocity over most of the region affected by the shock, which undoubtedly affected the accuracy of observations at the time in many places.

During the day of the earthquake and the one following the weather conditions were generally stormy over the region affected by the shock. It was prevailingly cloudy with rain or snow falling over much of the region affected, accompanied by winds of high velocity. Over much of the Shenandoah Valley region a blizzard (unusually strong wind accompanied by a nearly blinding heavy snowfall) was raging at the time of the occurrence of the earthquake. Early fruit trees (peaches, plums, etc.) were in full bloom, and the ground was covered with snow to a depth of ten inches in places, which drifted to such an extent as to make roads impassable.

Dr. P. C. Day, chief of the climatological division of the Weather Bureau, Washington, D. C., kindly furnished the writer with a rough copy of a manuscript chart prepared at his office showing weather conditions at 8 p.m., April 9, 1918, about one hour before the earthquake occurred. The chart shows a well developed area of a deep "low" centered at Hatteras off the Carolina coast, with steep isobaric gradients to the south, southeast, and east, on the north and west sides of the "low." Range in temperature over most of the region affected by the shock was from 30 to 40 degrees, and in pressure from 30.2 to 29.9. Comparing this chart with the map published twelve hours later (8 a.m., April 10, 1918), the "low" had diminished in intensity and had moved north and west to a position between Norfolk and Richmond, Va.

SUMMARY OF GEOLOGY AND CONCLUSIONS

Since, from the reports received, the shock seems to have been most severe in the northern part of the Valley of Virginia, a very brief summary of the geology of the northern valley region is of some interest in seeking the probable cause of the earthquake. The Valley of Virginia is bounded on the southeast by the Blue Ridge, the central portion of which is composed of pre-Cambrian igneous rocks and on the northwest by the Valley Ridges subprovince of folded sedimentary rocks ranging up to Devonian and Mississippian in age.

The valley maintains an approximate width of twenty miles from the state boundary southwestward to nearly the latitude of Greenville, Augusta County (Map, Plate I). From near the latitude of Strasburg and Riverton to that a short distance south of Harrisonburg, the valley is divided lengthwise by Massanutten Mountain, which is synclinal in structure and composed of sedimentary rock ranging up to and including Devonian in age. The mountain extends southwestward for a distance of about forty-five miles, and divides the valley lengthwise into two narrow valleys which average from five to ten miles in width. The Massanutten syncline, however, which involves the Martinsburg shale (Ordovician) at the surface, continues for a considerable distance both to the northeast and to the southwest of the north and south ends of the mountain proper.

The valley bottom is developed on folded limestone and shales of Cambro-Ordovician age, underlain by quartzites, sandstones, and shales of Lower Cambrian age which, because of their structure and

After the introduction of self-recording variometers, giving a continuous photographic record of the variations of the earth's magnetic elements, it was noted from time to time that the magnetograms at different observatories showed a peculiar disturbance at the time of an earthquake, even at a considerable distance from the origin of the shock. It was not until about thirty years ago, however, that the question of the relation between seismic and magnetic disturbances was given serious consideration. The Riviera earthquake of February 23, 1887, was recorded by most of the magnetographs of Europe and gave rise to much speculation as to the manner in which the disturbance of the instruments was produced, whether mechanical, magnetic, or electrical.[1] The fact that the disturbance was not recorded simultaneously at all of the observatories and appeared later as the distance from the source of the disturbance increased, pointed strongly to the conclusion that the effect recorded was mechanical. It was not clear, however, how a shaking of the ground could cause the oscillations of a suspended magnet. Moureaux thought to decide whether the effect was mechanical or magnetic by setting up on the pier supporting the horizontal intensity magnet, at Parc St. Maar, a copper bar of the same form and size mounted in the same way and with the same orientation. At the time of subsequent earthquakes, the magnet oscillated but the copper bar did not and Moureaux and Mascart thought that this result precluded a mechanical explanation of the phenomenon. As will be seen later, the fact that the magnet oscillated while the copper bar did not was due only indirectly to the magnetic property of the magnet. At Perpignan the Riviera earthquake was recorded on the magnetograph at $5^h\,47^m$ p.m. At 6 p.m. observations of the direct eye-reading apparatus were made and it was noted that the magnets were bobbing up and down but were not moving horizontally. Two and a half hours later, while making oscillation observations, it became necessary to discontinue because of the vertical bobbing of the magnet. The observer at once went to the eye-reading apparatus, and found that there also the magnets were bobbing up and down. This time corresponded with the third shock of the Riviera earthquake.

Another feature which added to the difficulty of the problem was the fact that not all of the magnets at the different observatories were disturbed at the time of an earthquake. At some observatories no change at all was noted, while at others some of the magnets were disturbed and others were not. At that time there were not many seismographs in operation, so that a comparison with the seismograph records was not in general possible. After that time the phenomenon was noted on many occasions and the problem engaged the attention of many magneticians, who in general concluded that the oscillations of the magnet were due to mechanical vibrations, basing their conclusion on the fact that the magnets were affected at the time of the arrival of the principal portion of the earthquake vibrations as recorded by the seismographs.

---

[1] *Comptes Rendus,* **104**, 1887.

In 1898 John Milne,[2] hoping to throw light on the subject, prepared a list of large earthquakes recorded by seismographs at widely distributed observatories from 1889 to 1897, and sent it to various magnetic observatories with a request that the magnetograms for the specified times be examined for possible earthquake effects. A study of the reports received leads to the conclusion that most of the observers reported ordinary magnetic disturbances, such as can usually be found within a few hours of any specified time. The results were so inconclusive that Milne considered that it would be necessary to have records from a seismograph and magnetograph operated at the same place in order to secure definite results.

Records of this nature have since become available by reason of the installation of seismographs at a number of magnetic observatories. In North America this has been the case at Toronto since 1897; at Cheltenham, Md., since December, 1904; at Vieques, P. R., since September, 1903; at Sitka, Alaska, since April, 1904; at Tucson, Arizona, since September, 1910. In April, 1903, a Milne seismograph belonging to the British Association was transferred from the Oahu College to the Honolulu Magnetic Observatory.

In 1904, J. E. Burbank,[3] then of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, undertook a systematic examination of the magnetograms of the magnetic observatories of the United States Coast and Geodetic Survey for the purpose of comparing the records of seismic disturbances made on them with the records of seismographs in the United States. In addition to the records of the seismographs at the observatories, there were available for comparison the records of the Bosch-Omori seismograph operated by the Weather Bureau at Washington, and of seismographs of the Milne type in operation at Baltimore, Toronto, and Victoria.

---

[2] Report of the British Association, 1898.

[3] "Earthquake disturbances recorded on the magnetographs at the observatories of the United States Coast and Geodetic Survey." *Terrestrial Magnetism*, September, 1905.

The effect produced by a seismic disturbance on the magnetogram is characteristic and quite different from ordinary magnetic disturbances. Burbank, in his paper on the subject, differentiates four different types; namely: First, those in which the disturbance begins abruptly and quickly reaches a maximum, dying down gradually (usually the case in nearby earthquakes); second, in which a small preliminary effect precedes the principal portion, in which there are often two or more maxima; third (by far the most common), those consisting of a small diamond-shaped disturbance; and fourth, those in which the trace is simply blurred and broadened.

He found that there were a considerable number of earthquakes which were recorded both by the magnetograph and the seismograph, the time of the record on the magnetographs of the Adie type, with heavy magnets, corresponding closely with the principal portion (large waves) of the seismograph record. In the case of the Eschenhagen magnetographs, with very light magnets, more earthquakes were recorded and the motion usually began a little in advance of the large waves. He also found that some earthquakes were recorded by the magnetograph and not by the seismograph, and vice versa, and that sometimes one variometer of a magnetograph was affected and not the others, as was the experience in the early investigations in Europe. In this connection it should be borne in mind that different seismographs are not equally effective in recording the earth's motion, and that it sometimes happens that only one of two components of a seismograph records a distant earthquake. Mr. Burbank found a considerable number of days on which there were a number of disturbances having the same characteristics as those which corresponded in time with earthquake disturbances. Some of these were traceable to local earthquake shocks felt in different parts of the country. Most of them, however, occurred on days when no earthquake movements had been reported. In later years a large number of these disturbances were recorded on days of severe thunder storms. It is probable that the concussion of the air incident to the electrical discharge was sufficient to shake the ground locally, and thus produce an effect corresponding to an earthquake disturbance.

In 1906, L. A. Bauer[4] made a study of the records of the San Francisco earthquake of April 18, 1906, obtained on the seismographs and magnetographs at the magnetic observatories of the United States Coast and Geodetic Survey, and found that the beginning of the disturbance occurred on the magnetographs at the same time as the beginning of the long waves on the seismograph. For some reason the earthquake was not recorded on the magnetograph at Porto Rico.

None of these investigations, however, gave a satisfactory explanation of the manner in which a shaking of the support of the magnet could produce an oscillatory motion. In a paper published in the *Journal of Terrestrial Magnetism* in 1914,[5] Professor Harry Fielding Reid, of Johns Hopkins University, presented a mathematical discussion of the subject in which he showed that both horizontal and vertical mechanical vibrations are capable of causing oscillations of recording magnets, by reason of the fact that the center of gravity of the suspended magnet does not coincide with the center of suspension, or point about which the system oscillates. He found in particular that there are two periods for horizontal and one for vertical disturbances which will cause marked oscillations of a unifilar magnet; that there are two periods for horizontal and three for vertical disturbances that will cause marked oscillations of a bifilar magnet; and, finally, that there are two periods for horizontal and two equal periods for vertical disturbances which will cause marked oscillations of a magnetic balance. The period of the disturbance must be very close to the proper value in order that the effect may be cumulative; in order, therefore, that a disturbance of small amplitude may make a clear record on the magnetic trace; and this seems to be one reason why the responses of recording magnets to earthquake disturbances are so variable. Reid's results show why it was that the copper bar used by Moureaux in his experiment did not oscillate at the time of an earthquake, although the magnet did. The center of gravity of the copper bar coincided with the center of suspension, and therefore no oscillatory motion was produced by the seismic motion of the ground.

---

[4] "Magnetograph record of earthquakes with special reference to the San Francisco earthquake of April 18, 1906." *Terrestrial Magnetism*, September, 1906.

[5] "The free and forced vibrations of a suspended magnet." *Terrestrial Magnetism*, June and December, 1914.

Reid gives credit to Charles Davison for the first approximately correct explanation of the manner in which a magnet is caused to oscillate by earthquake disturbances. In 1885 Davison pointed out that one end of the compass needle would receive a greater impulse than the other at the time of an earthquake shock on account of its greater mass. Later he showed that in order that a bifilar magnet may remain in a horizontal position, its center of gravity must be at unequal distances from the two points of support.

Lizmar, in 1895, gave a correct explanation of the manner in which oscillations of a unifilar magnet or a magnetic balance may be produced by a seismic disturbance.

The investigations of Burbank and Reid show conclusively that the majority of the peculiar disturbances recorded by magnetographs at the time of an earthquake disturbance are produced mechanically. There is some evidence, however, that there may be a true magnetic disturbance occurring at the time of an earthquake, either resulting from the earthquake movement or from the same cause which produced the earthquake movement. Thus the earthquake of June 12, 1897, disturbed the declination magnet at Bombay, giving fourteen distinct waves in twenty-nine minutes, the natural period of the magnet being 5.33 seconds. Regarding this earthquake, Milne states that a strong disturbance was recorded at nearly every magnetic observatory in Europe which arrived at those stations some time in advance of the large seismic waves, or rather about the time the preliminary tremors were recorded on the seismographs.

Probably the best record of long-period waves is one obtained by C. C. Farr[6] at the magnetic observatory at Christchurch, New Zealand, in November, 1901. On the morning of November 16th, Christchurch was visited by a severe shock of earthquake. The magnetograph at the Christchurch Observatory, though in adjustment, was not recording at the time. On visiting the observatory shortly after the first shock it was found that the vertical-force instrument had been thrown out of adjustment, while the others remained undisturbed. As it seemed probable that there would be other earthquake shocks than the first, it was decided to attempt to record some of them by running the magnetograph at high speed. This was done from about noon on the 16th until 7:30 p.m. of the 17th, when the supply of paper ran out, and from 11 a.m. on the 18th until 6 p.m. on the 20th. When arranged for running at high speed, the drums of the magnetograph revolved at the rate of nearly four millimeters per minute.

---

[6] "Records of earthquakes on quickly driven magnetographs." *Terrestrial Magnetism*, December, 1902.

In this way four shocks were recorded, all of them perceptible to some of the residents of the Cheviot District. There were also on the sheets many small sudden irregularities which could scarcely be ascribed to ordinary magnetic phenomena. The records of the declination instrument are all of the same general character and show waves of practically the same period of 137 seconds. On the horizontal-force variometer waves having a period of between 41 and 42 seconds were present in each case. The natural period of the magnets was 10.34 seconds in the case of declinaton, and 13.07 seconds in the case of horizontal intensity. The Milne seismograph in Wellington showed a series of comparatively small tremors during most of the periods when the magnetograph was being driven at high speed. There was one small tremor corresponding to one of the four disturbances recorded on the magnetograph, but there were many tremors larger than this on the seismograph record which were not recorded at all by the magnetographs. It seems possible that this may have been a real magnetic effect of the earthquakes.

Yamasaki, in a paper in 1901 on the relation between seismic and magnetic disturbances, stated that investigations in Japan covering a period of ten years showed that magnetic disturbances almost always occur a few days before violent earthquakes.

G. B. Rizzo,[7] from a study of the records obtained on the magnetographs of numerous observatories at the time of the Calabrian earthquake on September 8, 1905, concludes that the earthquake disturbed the majority of magnetographs within 1900 kilometers of the epicenter, the time of the disturbance, within the limits of the error of determination, coinciding with the principal portion of the seismic disturbance, and that it was probably produced by the movement of the ground at the site of the observatory. He suggests that this motion of the ground may have been transmitted to the magnet either directly (mechanically) or indirectly through the modification of the local magnetic field for a brief period. He points out that great volcanic eruptions which alter profoundly the electrical condition of the earth and air are sometimes accompanied by notable magnetic disturbances, as in the case of the eruption of Mont Pelée in 1902. In the case of this eruption, which was made the subject of special study by L. A. Bauer, it was found that a severe magnetic disturbance began abruptly at the time of the eruption, as nearly as could be determined from the information obtainable, and that this disturbance was recorded all over the globe, the times of beginning at the different magnetic observatories showing a variation of only a few minutes. Rizzo suggests that an earthquake may be accompanied or preceded by a disturbance of the electrical state of the earth or air, which may affect the earth's magnetic field.

---

[7] "Sopra le perturbazioni magnetiche dovute al terremoto della Calabria dell' 8 Settembre, 1905." *Terrestrial Magnetism*, September, 1906.

From the cases cited, it seems possible that there may be at times a real magnetic disturbance associated with an earthquake, but the evidence available is as yet so limited that it is impossible to say conclusively whether the association is accidental or whether the two phenomena are traceable to the same source.

To summarize: A great many earthquakes are recorded mechanically by magnetographs, the disturbance of the magnets usually occurring at the time of the principal portion of the seismic motion, though in some cases it begins a little earlier.

Magnetographs appear to be more sensitive to certain types of earthquake waves (particularly local shocks) than some seismographs.

It is possible that a real magnetic disturbance may sometimes be associated with an earthquake, though the evidence as yet presented is not conclusive.

GREAT EARTHQUAKE AND TIDAL WAVE IN SOUTHERN MINDANAO, P. I.

By Miguel Saderra Masó

On August 15, 1918, at 12^h 20^m 28^s (G. M. T.), a great seismic disturbance was recorded at Manila, the origin of it being at a distance of about a thousand kilometers. Subsequent telegraphic reports showed that the whole island of Mindanao had been violently shaken by an earthquake of very long duration. The epicenter, as far as it could be inferred from later reports, was in the Celebes Sea between the 124th and 125th meridians east, and the parallels 5° and 6° north.

The number of aftershocks during the successive days was so great that the Observatory at Manila, a thousand kilometers distant, recorded fifty-one of them to the end of August. At the station of Butuan, situated in Mindanao at about 450 kilometers north northeast from the center a Wiechert seismograph recorded 599 during the same period, about 250 of which occurred on the 15th and 16th.

In September, word came from the Philippine constabulary officers stationed at Lebak and Glan, stating that the earthquake had caused great damage in the southern country, facing Celebes Sea, between Cotabato and the Davao Gulf; and that it had been followed by a tremendous sea wave which swept the whole coast between Lebak and Glan, completing the destruction caused by the shocks. All the devastated country is inhabited by Moros and wild tribes, so the real amount of damage and number of casualties is not yet, and probably never will be, known. The following reports published by the local press refer only to the Sarangani Bay and to the vicinity of Port Lebak, where constabulary posts exist and some white men live. The town of Glan is situated at the entrance of Sarangani Bay, while Port Lebak lies about a hundred miles to the northwest:

> Captain Malone of the Philippine constabulary stationed at Glan, Cotabato, reports that the earthquake which occurred on the night of August 15th, last, destroyed all houses in Sarangani Bay and so far as known killed forty-six people. He reports that the earthquake lasted for three minutes and ten seconds and was later followed by a tidal wave reaching as high as twenty-four feet at some points and at the constabulary station at Glan to the height of

eighteen feet, thereby destroying all of the houses that had been shaken down by the shock and drowning a number of people, cattle, horses and other domestic animals and destroying all of the food supply of those living near the beach and all of the crops on the low lands. All native vintas were either destroyed or taken out to the sea. Large rivers were completely obliterated and new ones created. He further reports that a slide occurred on one of the large mountains adjacent to Sarangani Bay and it is his opinion that a number of wild people living at the foot of the mountain were buried, but as yet no definite reports have come in.

L. B. Kidwell, who has a saw-mill at Port Lebak, reports that the tidal wave at his place was between six and eight feet, killing six people and carrying a number of logs quite a distance inland. Light earthquakes have been almost continuous since August 15th both at Sarangani, Lebak and Cotabato, but no further damage has been done.

Another report says:

To the south of Port Lebak for some forty miles (I know nothing farther south) there was a tidal wave variously estimated at from twenty to twenty-five feet by Moro loggers who know what these measures are. Several Moros were drowned.

THE NEW ZEALAND EARTHQUAKE OF AUGUST 6, 1917

By P. G. Morgan

About 3:22 a.m. (New Zealand mean time)[1] on Monday, August 6, 1917, an earthquake was felt over the greater part of the North Island. The shock was more severe in the Wairarapa and East Wellington district than elsewhere. At Castlepoint the lantern apparatus of the lighthouse was thrown out of position and much damaged. Many chimneys were overthrown in the Eastern Wairarapa district, while at Masterton and Carterton many chimneys were partly destroyed, and crockery, etc., thrown off shelves. At the Manawatu Gorge a slip took place, which blocked the railway line. At Wellington people were, in general, aroused from sleep, clocks stopped, and a few articles were thrown off shelves. A rumbling noise was heard by some observers. Among the more distant points where the shock was distinctly felt was Auckland. It was not felt by residents of Christchurch (South Island), but was clearly registered by the seismograph at the meteorological observatory. The chief motion recorded was very large and lasted three minutes. Tremors began at 3:21 a.m., and extended over an hour.

During the next few days numerous after-shocks were felt in the Wairarapa district. Some of these were severe, especially one, that occurred about 3:40 a.m. (or slightly later) on Tuesday, August 7th. This was felt over the whole eastern part of the North Island. Among the localities reporting the shock were Whakatane (Bay of Plenty) and Waihi (in Ohinemuri County, near the north end of the Bay of Plenty).

There can be no doubt that these various earthquakes originated in or near a zone of faulting that lies parallel to the east coast of the North Island (from Cape Palliser to East Cape) and about two hundred miles distant. The severe earthquakes that occurred in the Gisborne district during October and November, 1914, had their origin in the same belt. The notable earthquake of August 9, 1904, and many others experienced in New Zealand are also to be ascribed to crustal movements in this belt.

---

[1] New Zealand civil mean time is 11 hrs. 30 mins. ahead of Greenwich mean time. A proposal to advance it to 12 hrs. ahead of Greenwich has lately been made, and is receiving strong support.

Most of the statements made in the above paragraphs are founded on newspaper reports published on August 6th and the next few days.

Since the above was written Mr. George Hogben, M.A., C.M.G., has read a paper before the Geological Section of the Wellington Philosophical Society in which he states that the earthquake of August 6th (August 5th if Greenwich time be used) originated in a spot approximately 296 kilometers (184 miles) eastward of Wellington, and 456 kilometers (283 miles) northeast of Christchurch. This gives an origin somewhat nearer the coast than any of the previous earthquakes mentioned above.

ERUPTION OF MOUNT NGAURUHOE, NEW ZEALAND, OCTOBER-NOVEMBER, 1917

By P. G. Morgan

During the latter part of October, 1917, the volcanic cone of Ngauruhoe, in the central part of the North Island of New Zealand, showed increasing signs of activity. These were first observed about the 17th. On the night of Tuesday, October 23, an outburst of considerable intensity took place. A newspaper account states that huge clouds of ash and steam were emitted from the crater, and numerous earth tremors were felt. Clouds prevented observation for some days, but a still more violent eruption began about 9 p.m. on Saturday, November 2nd, and continued almost without cessation until 3 p.m. on Sunday. At times large masses of red-hot lava were thrown out of the crater, and according to one account lava actually flowed down the sides of the mountain. On the other hand persons who ascended the mountain on November 11th stated that no lava was emitted, and that the dark stream running down the northwest side was not lava, but black scoria ash, which from a distance had the appearance of a lava stream. The earth tremors were very strong, and felt for great distances from the mountain, for example at Taumarunui, 26½ miles to the northwest. Articles on shelves at the prison camp, six miles away, were thrown on the floor. Houses trembled, and many panes of glass were broken. The fiercer outbursts were accompanied by violent detonations and long reverberations. Until November 11th eruptions of varying intensity took place, but from November 12th the newspapers available give no particulars, and presumably noteworthy outbursts ceased to take place. The chief point of observation was Waimarino, a railway station 13½ miles west of the summit of Ngauruhoe.

Although the flow of lava from Ngauruhoe during the eruption is not authenticated, there is no doubt that masses of molten rock were ejected, and in falling assumed the form of pancakes. Mr. A. J. Baker, Public Works Engineer at Taumarunui, who ascended the mountain after the eruption, saw flattened masses of dark andesitic lava six feet in diameter. The last record of a lava flow from Ngauruhoe was during the eruption of 1869.[1]

Some of the boulders ejected during the eruption are said to have been of twenty-five tons weight. Extremely large boulders were observed half a mile to the north of the crater, and stones of considerable size reached the flat country on the western side of the mountain. It is reported that the crater was considerably altered in shape during the eruption.

---

[1] Thomas, A. P. W.: "Notes on the Volcanic Rocks of the Taupo District and King Country." *Transactions New Zealand Institute*, **20**, 306-311, 1888. See p. 308.

AFTERSHOCKS OF THE SAN JACINTO EARTHQUAKE OF APRIL 21, 1918

From data collected by Homer Hamlin of Los Angeles, California.

Following the earthquake of April 21, 1918, at San Jacinto and Hemet, Cal., reported in this Bulletin, volume 8, pages 45-73, aftershocks continued for several days throughout a large part of the area affected by the main shock. Some of these aftershocks are mentioned at page 60 of the report, but most of such disturbances have been accepted as a well known phase of all severe earthquakes, and but little account has been taken of them. The shocks mentioned in the following records appear to belong with the aftershocks of the San Jacinto earthquake, and are therefore brought together here under one head. No attempt has been made to gather a full record of all such aftershocks.

At Corona, Riverside County, Cal., a sharp shock was felt April 22, 1918, at 2:15 p. m. It is said to have lasted for nearly two minutes, and to have been violent enough to upset small objects, to crack chimneys, and to throw down plaster.

A mile and a half northwest of Wildomar, Riverside County, on April 26, 1918, at 10:30 a. m., there were three shocks within half a minute felt by everyone. There was the usual rattling of doors, windows, and loose objects, but no damage was done.

At Calipatria, Imperial County, Cal., a slight shock was felt by everyone on April 28, 1918, at 2:30 p. m. It lasted four or five seconds, but caused no damage.

On April 30, 1918, about 9:30 p. m. earthquakes occurred over a wide area in southeastern California, including the Imperial Valley, the eastern part of Riverside County as far as the Colorado River at Palo Verde and Yuma, Arizona. It seems probable that this was also an aftershock of the San Jacinto earthquake of April 21st, but there are reports enough to identify it as a distinct shock that was clearly discerned over a wide area, and especially well defined from Hemet southward along the axis of the San Jacinto fault and extending into Mexico. Reports collected upon this earthquake by Mr. Homer Hamlin come from the points mentioned in the table below.

IMPERIAL VALLEY EARTHQUAKE OF APRIL 30, 1918.

Location	Duration	Intensity R.-F. Scale	Notes
Ames (N.W. of Glamis)	30 sec.	———	Three shocks preceded by thunder
Brawley	15-30 sec.	IV-V	Continuous
Calipatria	10 sec.	IV	Continuous
Calexico	———	VII	………
Coachella	10-15 sec.	V+	………
Descanso, S. Diego Co.	3 sec. each	IV	Two shocks
El Centro	1¼ min.	VII	After 9:30 the shocks "came in droves" and kept it up until May 2d
Glamis, Imperial Co.	3 sec.	IV-V	One shock
Heber	———	V-VI	See text below
Hemet	"all night"	………	Small shocks numerous more than a week after April 21st
Holtville, Imperial Valley	10 sec.	V	Continuous
Imperial	………	VI	………
Mecca	………	IV+	Two shocks
Ogilby	few secs.	V	One shock
Palo Verde	30 sec.	V	One shock
Picacho, Imperial Co.	2 min.	VI	Two shocks
Potholes	10 sec.	IV	One shock
Warner Springs	4 or 5 sec.	V	Shocks for ten days before
Wister	2 sec.	IV	One shock
Yuma, Ariz.	5 sec.	IV	One shock

The following extracts are from a letter written by Mr. H. P. Messenger, of Heber, Cal., to Homer Hamlin, regarding the earthquake of April 30th:

HEBER, CAL., May 5, 1918.

My Dear Mr. Hamlin:

I should have replied to yours regarding several of these other quakes, but I have been extremely busy of late, and have hardly had time to do any writing. Since that bad one on the 21st of April we have had a more or less continued shaking down here. I am sorry I did not put down the dates, but about a week ago around 8:30 in the evening we had a very decided shock that seemed to me a lot worse than the one on the 21st. It came with a distinct rumble (to me the rumble always seems to come from the southwest), and the quake was upon us, and it was a corker, too. I grabbed the lamp in time to save it from tumbling off the table; a picture came crashing down, and as I got out of my chair the pictures on the north and south walls would alternately swing out into the room and the ones on the east and west walls swung and rubbed against the walls. Several dishes were overturned. So far I have never noticed a rumble during or after a quake. That same night I was wakened four or five times by different quakes. Some would have a rumble and hardly any shake. One came the other morning at about 5:30 a.m. I heard a slight rumble and the east end of the house gave a slight creak, and it must have been at least three-fifths of a second before I felt or heard the other end of the house. One of the men said he heard the rumble in the southeast, but I did not hear it.

Another feature of the one on April 21st was that long after the actual shaking was over there appeared a slight undulating as if one were on a ship. After that motion was imperceptible I watched a door that kept swinging back and forth through an arc of an inch at the outer side of the door. As it kept up so regular and active and did not die down for a minute I am sure the earth was still under a disturbance.

The only humorous feature was that Mrs. Messenger grabbed the baby up and rushed outside; and (afterwards) whenever a car was heard coming down the road she would mistake the exhaust rumble for a quake and make a mad sprint for the child and rush outside again. I must admit that they are a rather hair-raising affair with the house shaking to beat the band and it getting worse every second.

I went through the one we had three years ago and it sure twisted things up proper. . . . Very truly yours,

H. P. Messenger.

On May 1st, shocks were felt at 7:44 a.m. at the following places: at Calexico there was one shock with an intensity of about IV; at Holtville, Imperial, and Picacho the intensity seems to have been about IV. Replies to inquiries sent to Corona, Wister and Yucaipa show that the shock was not observed at those places. At Calexico shocks were also noted as follows: on May 1, 12:07 a.m., 12:59 a.m. 1:07 a.m., 5:40 a.m. Other shocks were observed at that place, but no note was made of the time.

At 9:25 p.m. on May 2d, a shock with an intensity of IV-V was observed by several persons at Campo in San Diego County.

At Coachella on May 8, 1918, two slight shocks were felt at 12:20 p.m. by persons at rest.

At Heber in the Imperial Valley on May 8th one light shock was felt at 2:30 a.m. by persons at rest.

Six miles southeast of Aguanga, Cal., one light short shock was felt at 4 p.m. on May 9, 1918.

At Hemet, Cal., a sharp shock was felt generally at 12:20 p.m. on May 11th.

At Calipatria, Cal., a shock lasting about ten seconds occurred May 11th at 1:05 a.m. No damage was done, but observers note that the shock was of an intensity of VI.

Three miles east of Heber in the Imperial Valley, a shock was felt at 1:30 a.m., May 12, 1918, lasting ten seconds.

At Calipatria, Cal., another shock was felt generally at 10:54 p.m. on May 12th, lasting four or five seconds.

At 9:45 a.m. on May 16, 1918, a shock was felt one and a half miles northeast of Hemet, Cal. Dishes, doors, and windows rattled, and ceilings cracked. The shock lasted about three seconds and was accompanied by a roaring sound. No damage was done.

Three and a half miles east of Heber, Cal., an earthquake was generally felt at 6:47 p.m. on May 20, 1918. It lasted only two or three seconds, but it was strong enough to cause the swaying of buildings, and was accompanied by a rumbling sound.

SEISMOLOGICAL NOTES

White Bluff, Wash., April 18, 1918.—An earthquake was felt at White Bluff, about seven miles west of Spokane, Wash., shortly after 1 o'clock p.m. on April 18th and lasted about four seconds. It rattled dishes and windows and was accompanied by a rumbling noise. A. M. Jung, curator of the seismograph at Gonzaga University at Spokane, reports that the time at his station was 1:13 p.m.

Simi, Ventura County, Cal., May 24, 1918.—A light shock was felt by persons at rest one and a half miles west of Simi, Cal., on May 24th about 8 p.m. No damage was done.

Benton, Cal., June 4, 1918.—Two gentle shocks were observed at Benton, Mono County, Cal., at 9:03 a.m. on June 4th, and lasted about ten seconds. The intensity appears to have been about IV, R.-F. scale.

Southern California, June 6, 1918.—An earthquake was felt June 6th, about 3:30 p.m., at several widely separated places over Southern California. For the following data we are indebted to Homer Hamlin, civil engineer, of Los Angeles: At Oak Grove, Riverside County, two shocks were felt, generally with swaying and creaking of buildings, and clouds of dust rose on the neighboring mountains. At Aguanga, thirty miles southeast of San Jacinto, this shock is said to have been the most severe experienced after that of April 21, 1918. Two distinct shocks were observed, but no damage was done. Four and a half miles southeast of Hemet the shock was felt by everyone, and it was sharp enough to crack plaster on the walls, to loosen rocks from the mountain side, and to crack the ground around large trees. At Hemet two distinct shocks were felt by everyone, but they do not seem to have been as severe as they were southeast of that town. At Corona, Riverside County, it was felt generally, and is supposed to have had an intensity of about IV, and was accompanied by subterranean rumblings.

At Baptiste, twenty-five miles southeast of Hemet, two quick, bumping shocks were distinctly felt by everyone, and were preceded by a rumbling sound.

At Coachella there seemed to be a few light tremors, ending with one heavy jerk. It was felt generally, and caused the swaying of buildings and trees; the surfaces of ponds were disturbed as if by something thrown into the water.

It was felt at Wister, eight miles west of Niland, as a single shock.

In the Cuyamaca mountains, twelve miles north of Descanso, two members of the U. S. Forest Service heard a distinct rumbling five seconds before the shock was felt. There was but one shock at that place, and that lasted six seconds.

At Noria (formerly Gray), Riverside County, two shocks are reported, lasting four seconds, and felt by everyone.

In the Imperial Valley it was felt by everyone three and a half miles east of Heber, but not at Glamis.

At Warner Springs, San Diego County, the shock lasted three seconds and was generally felt.

At Los Angeles the shock was felt by many, especially by persons at rest or on fourth or fifth floors. Pencils lying on a drafting board were rolled about.

Cahuilla, Cal., July 7, 1918.—At about 5:30 p.m. on July 7, 1918, a slight earthquake was felt at Cahuilla, Cal., by persons at rest. The intensity was estimated to be about III, R.-F. scale.

Cairo, Egypt, July 16, 1918.—British newspapers report a severe earthquake, but without damage, at Cairo on July 16, 1918, at 10:10 p.m.

Olancha, Cal., July 17, 1918.—A distinct earthquake shock was felt twelve miles southeast of Olancha, Inyo County, Cal., July 17, 1918. It was observed by persons at rest and lasted one minute, rattling dishes, doors, windows, etc. No damage was done; the exact hour of the shock is not stated.

Panama, July 20, 1918.—The Associated Press reports earthquakes in the region west of Panama on July 20, 1918, but without damage.

Johannesburg, S. Africa, July 21, 1918.—The Associated Press dispatches report several earthquake shocks on July 21, 1918, with damage to the mines.

Los Angeles, Cal., September 16, 1918.—A gentle earthquake was reported from Los Angeles on September 16, 1918, at 9:27 p.m., lasting for twenty seconds.

Pine Bluff, Ark., October 4, 1918.—The newspapers report earth tremors at Pine Bluff, Ark., at 3 o'clock a.m. on October 4th.

Porto Rico, W. I., October and November, 1918.—A very heavy shock of earthquake was felt in Porto Rico at 10:14 a.m. on October 11, 1918. Minor shocks were felt in great number for over a month, with pretty strong ones on October 24th at 11:43 p.m. and on November 12th at 5:44 p.m. The first shock caused much damage, which was increased by that of the 24th. The people were greatly alarmed, and at the request of the Secretary of War, who directs the affairs of the Insular Government, Professors Harry Fielding Reid and Stephen Taber went to the island to study the disturbance. After they had been over about two-thirds of the island they made a preliminary report to the Governor, which was published in the local papers, and from which we make the following extracts:

"We believe the earthquakes were due to fractures of the rock in the northern part of Mona Passage, not far from the northwestern part of the Island of Porto Rico, and that the fracture which caused the shock of October 11th was accompanied by a small vertical displacement of a very limited area of the sea bottom, causing the sea wave which rose along the shores soon after the shock. Displacements of this kind are not uncommon, and portend no great disaster to Porto Rico. The shocks, though severe, were distinctly less violent than many shocks that have occurred in other parts of the world; for example, than the Charleston earthquake of 1886, or the California earthquake of 1906.

"The damage done by the shocks was greatest in the western part of the island and diminished progressively, though not uniformly, towards the east. On soft alluvial soils it was greater than on more solid foundations in the same neighborhood.

"The character of the construction of the buildings was responsible for the great destruction wrought. Buildings of 'mamposteria' suffered most, and brick buildings nearly as much; the extremely poor quality of the mortar used (in some cases it was scarcely stronger than dried mud) made these buildings exceptionally weak. Next in order came block concrete buildings and then those of concrete not reinforced. Well-made reinforced concrete buildings suffered no serious injury even in the regions where the shock was strongest. Wooden buildings and the small native huts, by yielding to the shock, were not damaged. . . .

"The sea wave, which followed the earthquake of October 11th, was of course confined to the coasts. Near Point Borinquen it attained a height of about twenty feet and drowned several people; it destroyed some native huts and some cocoanut trees. At Aguadilla a number of people were drowned and native huts were carried fifty or a hundred feet inland. At Mayaguez huts were moved. No damage seems to have been done by the wave elsewhere.

"All strong earthquakes are followed by aftershocks, which gradually die out in strength and in number. Sometimes there is but a single strong shock; sometimes, as in the recent shocks here, there are several. But strong shocks never continue indefinitely; quiet is always restored after a more or less short time. The aftershocks here have grown infrequent and very light; and, although the general knowledge of earthquakes does not justify a definite prediction, we think the indications are that the present disturbance is reaching its end. There is certainly no special reason for expecting another strong shock in the near future."

Corfu, Wash., November 1, 1918.—A. M. Jung, seismological observer at Gonzaga University at Spokane, Wash., communicates the following note from C. H. Aldrich of Corfu, a station on the Chicago, Milwaukee Railway 135 miles west of Spokane, in regard to an earthquake at that place: "The first shock was on November 1st, between 9:15 and 9:30 a.m. This was the most severe and lasted several seconds; it shook goods from the shelves and caused landslides for several miles along the hills. We have had on an average about three shocks every twenty-four hours since, but lighter." The intensity is estimated at IV of the R.-F. scale.

Italy, November 10, 1918.—An earthquake is said to have occurred November 10, 1918, in the mountains east of Florence. The village of Bagno di Romagna was damaged, and at the village of Santa Sofia a church collapsed, killing eight persons.

Jamaica, W. I., November 11, 1918.—In the district of Portland, Island of Jamaica, an earthquake was felt November 11, 1918. The exact time is not given; no damage was done.

Venice, Cal., November 19, 1918.—Two or three earthquake shocks were felt at Venice, Ocean Park, Santa Monica, Sawtelle, Hollywood and Redondo at 12:15 p.m. on November 19, 1918. Dr. James T. Brown of Venice reports that two shocks were felt by everybody at that place, and that they were accompanied by sounds resembling explosions. Similar explosion-like sounds were observed in Santa Monica Bay.

Tahiti, November 20-22, 1918.—Several earthquakes are reported from the island of Tahiti and at sea sixty miles off the Society Islands, November 20 to 22, 1918.

Copiapó, Chile, December 4, 1918.—A severe earthquake occurred in the province of Atacama, Chile, December 4th, affecting the area between Vallenar and Taltal in the province of Antofagasta. Much damage is said to have been done to railways and other property, but details are lacking. The shocks were recorded by the seismographs at Vancouver, Ottawa, Washington, and elsewhere.

New Seismological Station.—Central America is a region of very considerable seismic activity, but it has always been difficult to obtain accurate and scientific reports of the disturbances occurring in that region. It is therefore gratifying to know that a seismological station is to be established there, as will be seen from the following note recently received from the Director of the Georgetown Seismological Observatory:

"The establishment of a coöperative seismological station in Guatemala City, Guatemala, has been determined upon by Francis A. Tondorf, S.J., Director of the Georgetown Seismological Observatory. This station will be in charge of Mr. Claudio Urrutia, chief consulting engineer of the Guatemalan government. It is expected that reports from this center will be available on or about March 1st. Bulletins will be dispatched directly from Guatemala."

Two Unique Records.—According to a letter recently received from Dr. Otto Klotz, Director of the Dominion Astronomical Observatory, Ottawa, Canada, the public of that city had been advised that the abdication of the Kaiser and the signing of the armistice would be announced, as soon as the news arrived, by two blinks on the electric light circuit throughout the city for the first event and four blinks for the second event. As the seismograph records photographically and as the city light is used, obviously any blinking of the light would be recorded, as is shown on copies of the two seismograms kindly sent by Dr. Klotz.

Shoddy Buildings.—The manner of constructing buildings, in any country subject to seismic disturbances, is one of great importance and it is hoped that something will be done soon toward making more stringent laws concerning building design and construction.

A prominent California architect, to whom was sent a reprint of the articles on the San Jacinto earthquake printed in the preceding number of this BULLETIN, writes as follows on this subject:

> I especially appreciate the photographs of the wrecked buildings and am going to use them in the future in an attempt to get some improved legislation on the architects' license law in this state, which will make it a crime to construct such shoddy buildings as these pictures evidence.
>
> The architects endeavored at the last session of the legislature to have some improvements in our license law, but it was difficult to impress the members of the legislature with the importance of holding someone responsible financially and criminally for the results of the careless and shoddy construction of buildings. These photographs would have been most convincing.

SEISMOLOGICAL REPORTS RECEIVED

AMERICA

Cambridge, Mass. Harvard University—Record of the Seismographic Station from May 25 to October 31, 1918.

Denver, Colo.—Jesuit Seismological Service, Sacred Heart College. Reports nos. 7 to 11, from August 1 to November 30, 1918.

Ithaca, N. Y. Cornell University—Seismograph Station, Department of Geology. Reports nos. 84 to 88, August 1 to November 30, 1918.

La Paz, Bolivia.—Boletin Sismico del Observatorio del Colegio San Calixto (PP. Jesuitas). Reports nos. 1 to 18, 20 to 41, January to October 19, 1918.

Ottawa, Canada.—Earthquake Station, Dominion Astronomical Observatory. Reports 12 to 27, from July 1 to November 30, 1918.

Washington, D. C.—Georgetown University. Seismological Bulletin, Department of Geology, nos. 40 to 43 bis bis, from July 1 to October 31, 1918.

EUROPE

Barcelona, Spain.—Estacion Sismica del Observatorio Fabra de la Real Academia de Ciencias y Artes, nos. 48 to 53, from May 1 to August 31, 1918.

Coimbra, Portugal.—Boletin Sismico do Observatorio da Universidade, nos. 5 to 8 cont. from May 1 to September 30, 1918.

PHILIPPINE ISLANDS

Manila, P. I.—Seismological Bulletin of the Observatory, nos. 7 to 30, from March 1 to September 30, 1918.

PUBLICATIONS RECEIVED

G. Agamennone.—"Contributo alla teoria del pendulo orizontale." Est. Reale Accademia dei Lincei, **27**, 326-331. Seduta del 5 maggio, 1918.

G. Agamennone.—"Sulla natura del 10 impulso del terremoto Marsicano del 1915." Est. Reale Accademia dei Lincei, ***27***, 65-69. Roma, agosto, 1918.

Octavio Bustamente.—"Jefe del Servicio Meteorologico y Sismologico Mexicano."—***Boletin Mensual del Observatorio Meteorologico y Sismologico Central de Mexico,*** Tacubaya, D. F., nos. 1, 2, 3 y 12, 1918.

Comte de Montessus de Ballore.—"Du rôle comparé des diverses nationalités dans les progrès de la sismologie moderne." Est. del ***Bollettino della Società Sismologica Italiana,*** **20**, 3-12, Modena, 1916.

F. Omori.—"The eruptions and earthquakes of the Asama-Yama." "Lists of the volcanic disturbances instrumentally registered at the Asama-Yama Seismological Stations, 1913 to 1916." ***Bulletin of the Imperial Earthquake Investigation Committee,*** **7**, no. 2, Tokyo, March, 1917.

F. Omori.—"Vibration of reinforced concrete chimneys." "On the relation between the duration of the preliminary tremor and the epicentral distance for near earthquakes." ***Bulletin of the Imperial Earthquake Investigation Committee,*** **9**, no. 1, Tokyo, March, 1918.

J. Scherer.—***Bulletin Annuel de l'Observatoire Météorologique du Séminaire***—College St. Martial, Port-au-Prince, Haiti, An 1917; Bul. Sismologique, pp. 129-131. (Haiti), 1918.

Weather Bulletin, December, 1917.—Catalogue of Philippine earthquakes, 1917.

OFFICERS OF THE SEISMOLOGICAL SOCIETY OF AMERICA

C. F. Marvin	*President*
C. F. Tolman, Jr.	*First Vice-President*
Otto Klotz	*Second Vice-President*
H. O. Wood	*Third Vice-President*
S. D. Townley	*Secretary-Treasurer*

BOARD OF DIRECTORS

J. C. Branner
W. W. Campbell
Otto Klotz
A. C. Lawson
A. G. McAdie
C. F. Marvin
H. F. Reid
R. W. Sayles
C. F. Tolman, Jr.
S. D. Townley
H. O. Wood
J. B. Woodworth

FINANCE COMMITTEE

J. C. Branner
C. F. Tolman, Jr.
S. D. Townley

AUDITING COMMITTEE

J. K. Moffitt
Bernard Benfield
Otto von Geldern

PUBLICATION COMMITTEE

J. C. Branner
A. C. Lawson
R. W. Sayles
S. D. Townley

SCIENTIFIC COMMITTEE

Otto Klotz
T. A. Jaggar, Jr.
A. G. McAdie
C. F. Marvin
F. L. Odenbach
A. H. Palmer
H. F. Reid
C. F. Tolman, Jr.
Count de Montessus de Ballore

(The first named of each committee is the chairman. The president is ex-officio a member of all committees.)

MEMBERS OF THE SEISMOLOGICAL SOCIETY OF AMERICA

December 15, 1918

(Life member indicated by asterisk.)

Adams, Frank D.........................McGill University, Montreal, Canada
Aguilera, José G.........................Mexicali, Mex.
Ahern, M. J. (S.J.).........................Boston College, Chestnut Hill, Mass.
Anderson, Robert Van Vleck.........................Menlo Park, Cal.
Arnold, Ralph.........................925 Union Oil Bldg., Los Angeles, Cal.
de Ballore, Count de Montessus....Servicio Sismolojico, Santiago, Chile
Barbour, Edwin H.........................University of Nebraska, Lincoln, Neb.
*Bascom, Florence.........................Bryn Mawr College, Byrn Mawr, Pa.
Bauer, L. A.....Dept. Terrestrial Magnetism, 36th St. and Broad Branch Road, Washington, D. C.
Beeson, J. J.........................Alta, Utah
Benfield, Bernard.........................Rialto Bldg., San Francisco, Cal.
Benson, Oscar A.........................Albert City, Iowa
Berloty, B. (S.J.)..Observatoire de Ksara, Saadnail par Beyrouth, Syrie
Bicknell, Ernest P.........................715 Union Trust Bldg., Washington, D. C.
Bingham, A. C.........................218 Fifth St., Marysville, Cal.
Blackshear, Edward L.........................Prairie View College, Prairie View, Tex.
Blain, J. (S.J.).........St. Boniface College, St. Boniface, Manitoba, Can.
*Blanding, Gordon.........................Belvedere, Cal.
Blaney, Chas. D.........................Saratoga, Cal.
*Board of Fire Underwriters of the Pacific, 914 Merchants Exchange Bldg., San Francisco, Cal.
Boggs, Edward M.........................Box 496, Oakland, Cal.
Boutwell, John M.........................1323 De la Vina St., Santa Barbara, Cal.
*Branner, J. C.........................Stanford University, Cal.
Branscomb, J. H.........................122 W. Granite St., Butte, Mont.
Brennan, J. F.........................Kingston, Jamaica, West Indies
Brooks, C. F.........................Yale Station, New Haven, Conn.
Brown, Chas. W.........................37 Barnes St., Providence, R. I.
Brown, E. Call.........................Sierra Madre Club, Los Angeles, Cal.

Brownhill, J. S. .... Negril P. O., Jamaica
Bunyan, F. W. .... Heroult, Shasta Co., Cal.
Burbank, Luther .... Santa Rosa, Cal.
Burch, Albert .... Crocker Bldg., San Francisco, Cal
Butler, G. Montague .... University of Arizona, Tucson, Ariz.
Campbell, Douglas H. .... Stanford University, Cal.
Campbell, Leon .... Harvard College Observatory, Cambridge, Mass.
Campbell, W. W. .... Lick Observatory, Mt. Hamilton, Cal.
Carlsmith, Carl Schurz .... Hilo, Hawaii
Carney, Frank .... Lawrence, Kan.
de Carvalho, Anselmo Ferraz .... Faculdade de Sciences, Universidade Coimbra, Portugal.
Cebrian, J. C. .... 1801 Octavia St., San Francisco, Cal.
Chamberlin, Rollin T. .... University of Chicago, Chicago, Ill.
Chamberlin, T. C. .... University of Chicago, Chicago, Ill.
Chauvet, A. L. .... Am. Steel Box Co., 378 Water St., New York, N. Y.
Chu, C. C. .... 12 Sumner Road, Cambridge, Mass.
Cirera, Ricardo (S.J.) .... Tortosa, Spain
Clapp, Frederick G. .... 120 Broadway, New York, N. Y.
Cleland, Herdman F. .... Williams College, Williamstown, Mass.
Cobb, Collier .... Chapel Hill, N. C.
Coleman, A. P. .... School of Science, Toronto, Ontario, Canada
*Commercial Union Assurance Co., Ltd., 558 Sacramento St., San Francisco, Cal.
Cooke, Henry M. A. .... The Ooregum Mining Co. of India, Ltd., Oorgaum, Province of Mysore, India.
Cornish, Frank V. .... Underwood Bldg., San Francisco, Cal.
Costa, José .... 1926 Pine St., San Francisco, Cal.
Crandall, Roderic .... 47 Parliament St., Westminster, London, S. W. England.
Crook, A. R. .... Curator of State Natural History Museum, Springfield, Ill.
Crosby, W. O. .... Institute of Technology, Cambridge, Mass.
Crothers, George E. .... City Hall, San Francisco, Cal.
Cummings, Byme .... University of Utah, Salt Lake City, Utah.
Cushing, Chas. S. .... 821 First Natl. Bank Bldg., San Francisco, Cal.
*Daly, R. A. .... 23 Hawthorn St., Cambridge, Mass.
Dana, Edward S. .... New Haven, Conn.
David, T. W. Edgeworth, University of Sydney, N. S. W., Australia

Davis, E. F..........Bacon Hall, University of California, Berkeley, Cal.
De Golyer, Everette..............................65 Broadway, New York, N. Y.
Denison, F. Napier, The Observatory, Gonzales Heights, Victoria, B. C.
Derleth, C., Jr..............................University of California, Berkeley, Cal.
Dick, Frederick J..Point Loma, Cal.
Dole, A. R..Hammonton, Cal.
Dole, Chas. S..Lihue, Hawaii
*Drake, N. F........................University of Arkansas, Fayetteville, Ark.
Dunn, Orrin W..............................Box 104, Stanford University, Cal.
Durand, W. F..Stanford University, Cal.
Du Val, W. S........914 Merchants Exchange Bldg., San Francisco, Cal.
Eddy, A. J..2630 Fulton St., Berkeley, Cal.
Eells, Charles P..............................2415 Pierce St., San Francisco, Cal.
Ehrenfeld, Frederick..............College Hall, Univ. Pa., Philadelphia, Pa.
Einarsson, Sturla..Faculty Club, Berkeley, Cal.
Emerson, F. V..................Louisiana State University, Baton Rouge, La.
Everette, Willis Eugene........3512 South Eleventh St., Tacoma, Wash.
Fenner, Clarence N.............Geophysical Laboratory, Washington, D. C.
Fletcher, Chas. R..........................402 Stimson Bldg., Los Angeles, Cal.
Forbes, John F......................................Crocker Bldg., San Francisco, Cal.
Forstall, A. W. (S.J.)........College of the Sacred Heart, Denver, Colo.
Fowler, F. H......................................221 Kingsley Ave., Palo Alto, Cal.
Franklin, E. C..Stanford University, Cal.
*Fuller, M. L..................................134 West Upsal St., Germantown, Pa.
Gama, Alipio—Rua Curuzu, No. 58, Sao Christovao, Rio de Janeiro, Brazil.
Gauthier, H. (S.J.)..........Observatoire de Zi-Ka-Wei, Shanghai, China
von Geldern, Otto..........................865 Pacific Bldg., San Francisco, Cal.
George, R. D..845 Eleventh St., Boulder, Colo.
Gilman, C. E..851 Calmar Ave., Oakland, Cal
Glenn, L. C..................................Vanderbilt University, Nashville, Tenn.
Gordon, Adam R......................................San Juancito, Honduras, C. A.
Gordon, C. H........................University of Tennessee, Knoxville, Tenn.
Grant, Joseph D................................2200 Broadway, San Francisco, Cal.
Grasty, John S....................University of Virginia, Charlottesville, Va.
Green, J. W...................U. S. Coast and Geodetic Survey, Paonia, Colo.
Gunn, James A., Jr..Kelseyville, Cal.
*Haarmann, Erich..................................Apartado No. 1408, Mexico, D. F.
Haehl, H. L.................1315 Humboldt Bank Bldg., San Francisco, Cal.

Hall, Maxwell..........Montego Bay, Jamaica, West Indies
Hamlin, Homer..........1021 S. Union Ave., Los Angeles, Cal.
Harris, A. L..........1104 Central Bldg., Los Angeles, Cal.
Hassan, Ali A..........666 Mansfield Place (Flatbush) Brooklyn, N. Y.
Herrmann, F. C..........375 Sutter St., San Francisco, Cal.
Hershey, Oscar H..........Kellogg, Idaho
Hicks, A. R..........Twin Falls, Idaho
Hills, Thomas M..........1942 Inka Ave., Columbus, O.
Hitchcock, C. H..........2376 Oahu Ave., Honolulu, T. H.
Hoffman, F. L.....Prudential Insurance Co. of America, Newark N. J.
Hoge, Wendell P..........Mount Wilson, Cal.
Holmes, Howard C..........112 Market St., San Francisco, Cal.
Holway, R. S..........8 Bacon Hall, Univ. of California, Berkeley, Cal.
Hook, J. S..........Marland Oil Co., Ponca City, Okla.
Hoover, H. C..........Washington, D. C.
Hoover, Mrs. Lou Henry..........Stanford University, Cal.
Hope-Jones, Handforth..........P. O. Box 589, Lima, Peru.
Hoskins, L. M..........365 Lincoln Ave., Palo Alto, Cal
Hovey, E. O..........Amer. Museum of Nat. History, New York, N. Y.
Howe, Ernest..........Litchfield, Conn.
Huerta, Santiago de la..........Univ. Nacional de Cuba, Habana, Cuba
*Hussey, William J..........University of Michigan, Ann Arbor, Mich.
*Jacobitti, Eugenio..........Bari, Italy
Jaggar, T. A., Jr..........Hawaiian Volcano Observatory, Volcano House, Hawaii
Jamison, C. E..........P. O. Box 1300, Billings, Mont.
Jenkins, Olaf P..........Arizona State Bureau of Mines, Tucson, Ariz.
Johnston, A. W..........Dept. of Geology, University of Minnesota Minneapolis, Minn.
Jones, J. C..........University of Nevada, Reno, Nev.
Jung, A. M..........Ganzaga University, Spokane, Wash.
Keen, W. W..........1729 Chestnut St., Philadelphia, Pa.
Keesling, Francis V..........1205 Chronicle Bldg., San Francisco, Cal.
Kellogg, V. L..........Stanford University, Cal.
Kemp, J. F..........Columbia University, New York, N. Y.
Kimball, E. B..........284 Mountain Ave., Piedmont, Cal.
Klotz, Otto..........437 Albert St., Ottawa, Canada
Knecht, C. E..........Box 2269, Johannesburg, Transvaal, S. Africa
Koster, F. J..........22d and Illinois Sts., San Francisco, Cal.

Kroeck, L. S.........College of the Pacific, San Jose, Cal.
Lampland, Carl O.........Lowell Observatory, Flagstaff, Ariz.
Laughlin, Homer, Jr.........666 West 28th St., Los Angeles, Cal.
Lawrence, Samuel C.........7 Rural Ave., Medford, Mass.
Lawry, Geo. V.........1116 Boston Block, Salt Lake City, Utah
Lawson, A. C.........University of California, Berkeley, Cal.
Leib, S. F.........San Jose, Cal.
Lemos, Alix Correa.........National Observatory, Rio de Janeiro, Brazil
Lenox, Lionel R.........Stanford University, Cal.
Leuschner, A. O.........1816 Scenic Ave., Berkeley, Cal.
Lewis, Robert S.........University of Utah, Salt Lake City, Utah
Libbey, Wm.........Princeton, N. J.
Lietz, Adolph.........632 Commercial St., San Francisco, Cal.
Lindley, Curtis H.........604 Mills Bldg., San Francisco, Cal
*Lisboa, M. A. R.........426 Praia de Botafogo, Rio de Janeiro, Brazil
Lisson, Carlos I.........Casilla de Correos, No. 787, Lima, Peru
Loring, Conrad.........670 Southern Pacific Bldg., San Francisco, Cal.
Loring, Frank C.........Home Life Bldg., Toronto, Ontario, Can.
Louderback, Geo. D.........University of California, Berkeley, Cal.
Lynch, Edward.........R. D. No. 1, 365 A, Pasadena, Cal.
McAdie, Alex. G.........Blue Hill Observatory, Readville, Mass.
McCallie, S. W.........Atlanta, Ga.
McCaughern, J. C.........914 Merchants Ex. Bldg., San Francisco, Cal.
McCaughern, Thos.........914 Merchants Ex. Bldg., San Francisco, Cal.
McCune, Jas. N.........Box 745, Portland, Ore.
McLaughlin, A. C.........65 Market St., San Francisco, Cal.
Maddrill, James D.........997 Monadnock Bldg., San Francisco, Cal.
Mahoney, Daniel P. (S.J.).........College of the Holy Cross, Worcester, Mass.
Marsh, G. F.........Lone Pine, Inyo Co., Cal.
Masters, V. F.........316 Rialto Bldg., Kansas City, Mo.
Marvin, C. F.........U. S. Weather Bureau, Washington, D. C.
Masó, Miguel Saderra (S.J.).........Observatory, Manila, P. I.
Mather, Kirtley F.........School of Mining, Kingston, Ontario
Mendenhall, W. C.........U. S. Geological Survey, Washington, D. C.
Menke, J. H., Jr.........Maricopa, Cal.
Merritt, F. C.........Ramshorn Mine, Bay Horse, via Challis, Ida.
Miller, Benj. L.........Lehigh University, South Bethlehem, Pa.
Miller, Dayton C.........Case School of Applied Science, Cleveland, O.

Miller, Irving..........2942 Claremont Blvd., Berkeley, Cal.
*Moffitt, J. K..........First National Bank, San Francisco, Cal.
Morhardt, E. F.....914 Merchants Exchange Bldg., San Francisco, Cal.
Moore, E. S..........State College, Pa.
Moran, Robert B..........458 South Spring St., Los Angeles, Cal.
Morgan, Percy Gates..........Geological Survey Office, Wellington, N. Z.
Morize, Henrique..........Observatorio Nacional, Rio de Janeiro, Brazil
Mulholland, Wm..........Box 618, Station C, Los Angeles, Cal.
Naramore, Chester..........Bureau of Mines, Washington, D. C.
Negri, Galdino..........Observatorio Astronomico, La Plata, Argentina
Newsom, J. F..........Box 563, Palo Alto, Cal.
Nickel, J. Leroy..........Menlo Park, Cal.
Nolan, Edward J..........Academy of Natural Sciences, Philadelphia, Pa.
Ochsner, W. H..........713 Hobart Bldg., San Francisco, Cal.
Odenbach, F. L. (S.J.)..........St. Ignatius College, Cleveland, O.
Ogilvie, Ida H..........Barnard College, New York, N. Y.
O'Hara, Cleophas C...South Dakota School of Mines, Rapid City, S. D.
Ohern, D. W..........515 W. 14th St., Oklahoma City, Okla.
de Oliveira, Euzebio Paulo..........Servico Geologico, Ministerio da Agricultura, Rio de Janeiro, Brazil.
Olney, Warren, Jr..........1107 Merchants Ex. Bldg., San Francisco, Cal.
Orcutt, W. W..........1328 West Fifth St., Los Angeles, Cal.
Ordonez, Ezequiel..........2a General Prim 43, Mexico City, Mex.
Osborne, Clarence B..........care Calif. Highway Commission, Forum Bldg., Sacramento, Cal.
Osborne, H. Z., Jr..........City Engineer's Office, Los Angeles, Cal.
O'Shaughnessy, M. M..........2732 Vallejo St., San Francisco, Cal.
Pack, Frederick J..........University of Utah, Salt Lake City, Utah
Packard, Henry J..........420 Eddy St., San Francisco, Cal.
*Page, Charles..........Merchants Exchange Bldg., San Francisco, Cal.
Palmer, Andrew H..........U. S. Weather Bureau, 1500 Merchants Exchange Bldg., San Francisco, Cal.
Parkin, William M..........5577 Hampton St., Pittsburg, Pa.
Pearce, L. F..........San Juancito, Honduras, C. A.
Pemberton, J. R..........71 Clarendon Ave., San Francisco, Cal.
Perry, C. N..........P. O. Box A1, Calexico, Cal.
Perry, H. F..........Box 263, Palo Alto, Cal.
Phelan, James D..........Phelan Bldg., San Francisco, Cal.
Pirsson, L. V..........41 Trumbull St., New Haven, Conn.

Pratt, Wallace E.......Box 983, Wichita Falls, Tex.
Prouty, Wm. F.......Department of Geology, University, Ala.
Prowell, E. E.......Parke de la Sierra, R. F. D. No. 5, Phoenix, Ariz.
Ralston, Ivan R.......P. O. Box 444, Calexico, Cal.
Reed, Wm. G.......P. O. Box 242, Jamaica, N. Y.
Reeds, Chester A.......American Museum of Natural History, 77th St. and Central Park West, New York, N. Y.
Reid, H. F.......Johns Hopkins University, Baltimore, Md.
Ricard, Jerome S. (S.J.).......Univ. of Santa Clara, Santa Clara, Cal.
Rice, John A.......525 Market St., San Francisco, Cal.
Rice, Wm. North.......Middletown, Conn.
Richardson, D. S...128 Lick Bldg., 25 Montgomery St., San Francisco, Cal.
Ries, Heinrich.......Cornell University, Ithaca, N. Y.
Rixford, Emmet.......1795 California St., San Francisco, Cal.
Rizso, G. B.......Osservatorio, Messina, Italy
Roberts, Milnor.......4505 Fifteenth Ave., N. E., Seattle, Wash.
Robertson, G. M.......914 Merchants Ex. Bldg., San Francisco, Cal.
Rocha, Dias da.......Museu Rocha, Ceará, Brazil
Rogers, F. J.......Stanford University, Cal.
Rohani Thiurnal Raja.......Kighakke Kottaram Palace, Trivandrum, Travancore, S. India.
Rolfe, F.......1631 Council St., Los Angeles, Cal.
Ross, G. McM.......444 West Poplar St., Stockton, Cal.
Roxo, Mathias, de Oliveira.......Servico Geologico, Ministerio de Agricultura, Rio de Janeiro, Brazil.
Runyon, C. F.......589 Market St., San Francisco, Cal.
Ryan, Harris J.......Stanford University, Cal.
*Sayles, Robert W.......263 Hammond St., Chestnut Hill, Mass.
Scherer, J.......Port-au-Prince, Haiti, W. I.
Schrader, Gustave.......Box 72, Sutter Creek, Cal.
Schutt, R.......Papenhuderstrasse 8, Hamburg 24, Germany
Schwennesen, A. T.......Box 930, Cheyenne, Wyo.
Scott, A. H.......Lovelock Assay Office, Lovelock, Nev.
*See, T. J. J.......U. S. Naval Observatory, Mare Island, Cal.
Shattuck, George B.......Vassar College, Poughkeepsie, N. Y.
Shedd, Solon.......Pullman, Wash.
Sheldon, Pearl G.......Cayuga Heights, Ithaca, N. Y.
Shepard, E. M.......1403 Benton Ave., Springfield, Mo.

Shutts, Arthur B.........Poultney, Vermont

Sidgreaves, Walter (S.J.).........Stonyhurst College Observatory, near Blackburn, Eng.

Small, H. L.........Poultney, Vt.

Smith, Burnett.........Syracuse University, Syracuse, N. Y.

Smith, B. J.........641 Vernon St., Oakland, Cal

Smock, John C.........Hudson, N. Y.

Snyder, Irving H.........Los Gatos, Cal.

Soo-Hoo, Peter, Koushing Engineering Co., Howe Bldg., West Bund, Canton, China.

Soper, E. K.........Oregon Agricultural College, Corvallis, Ore.

Spalding, W. A.........134 North Gates St., Los Angeles, Cal.

Speight, R.........Canterbury College, Christchurch, N. Z.

Squire, John A.........Box 5, Palo Alto, Cal.

Stall, A. G.........1018 E. Augusta Ave., Spokane, Wash.

Stanford, Josiah W.........Warm Springs, Alameda County, Cal.

Starke, Eric A.........2655 Dwight Way, Berkeley, Cal.

Steel, Donald.........718 Bryant St., Palo Alto, Cal.

Stevens, F. A.........411 Waverley St., Palo Alto, Cal

Stevenson, A. E.........20 Nassau St., New York, N. Y.

Stoy, Sam B.........332 Pine St., San Francisco, Cal.

Sulzer, Elmer G.........Madison, Ind.

Sur, Forest John S.........609 Colfax Ave., Denver, Colo.

Surr, Gordon.........321 Eighth St., San Bernardino, Cal.

Symington, R. B.........404 Mills Bldg., San Francisco, Cal.

*Taber, Stephen.........University of South Carolina, Columbia, S. C.

Taff, J. A.........628 Cowper St., Palo Alto, Cal.

Taylor, Frank B.........2905 Fairfield Ave., Fort Wayne, Ind.

Templeton, E. C.........Downey, Cal.

Thiele, F. C.........1247 Cowper St., Palo Alto, Cal.

Tolman, C. F., Jr.........Stanford University, Cal.

Tondorf, Francis A. (S.J.).........Seismological Observatory, Georgetown University, W. Washington, D. C.

Townley, S. D.........Stanford University, Cal.

Townsend, Rex.........1416 Twentieth St., N. W., Washington, D. C.

Tristán, J. F.........Box 357, San José, Costa Rica

Turner, H. W.........634 Mills Bldg., San Francisco, Cal.

Udden, Anton D.........Box 326, Davenport, Ia.

Uhlig, Carl.........Room 18, Ferry Bldg., San Francisco, Cal.

*Van Horn, Frank R., Case School of Applied Science, Cleveland, O.
*Veatch, A. C..............19 Grosvenor Gardens, S. W. 1, London, Eng.
Vickery, Frederick Paul..........................367 Forest Ave., Palo Alto, Cal.
*Vietor, E. K..Box 555, Richmond, Va.
*Volz, F. W..Wyandotte, Okla.
Wagner, C. F......................204 Lumbermen's Bank Bldg., Portland, Ore.
Walcott, Chas. D..................Smithsonian Institution, Washington, D. C.
Waldron, Richard, Jr. 204 Citizens Nat. Bank Bldg., Los Angeles, Cal.
Waring, G. A...214 Cole Bldg., Tulsa, Okla.
Warthorst, Frank W..................R. F. D. No. 2, Box 7, Bakersfield, Cal.
Watson, T. L.........................University of Virginia, Charlottesville, Va.
Watt, Rolla V...201 Sansome St., San Francisco, Cal.
Weaver, Charles E..................University of Washington, Seattle, Wash.
White, Geo. F..Valdez, Alaska
Wigglesworth, Edward............................109 Chestnut St., Boston, Mass.
Williams, T. M.......................................351 Homer Ave., Palo Alto, Cal.
Willis, Bailey..Stanford University, Cal.
Wood, Harry O...Cosmos Club, Washington, D. C.
Woodward, Robert S..............65 The Dresden Apts., Washington, D. C.
*Woodworth, J. B.........................Geological Museum, Cambridge, Mass.
Wright, W. Q...Sausalito, Cal.
Wroth, James S..Chuquicamata, Chile, S. A.
Young, Roland...Montebello Oil Co., Fillmore, Cal.
Zeigler, Victor...Golden, Colo.

SUBSCRIBERS

American Geographical Society, The....................Broadway at 156th St., New York, N. Y.
American Philosophical Society, The..............................Philadelphia, Pa.
Amherst College Library..Amherst, Mass.
Augustana College and Theological Seminary, the Denkman Memorial Library of,...Rock Island, Ill.
Barnard, W. K..............................1105-6 Central Bldg., Los Angeles, Cal.
Boston Public Library..Boston, Mass.
Bureau of Mines, Library of..Toronto, Canada
California State Library...Sacramento, Cal.
Chief Astronomer, Interior Department...............................Ottawa, Canada
Cleveland Public Library, Order Department.........................Cleveland, O.

College of the Pacific....San Jose, Cal.
Colorado School of Mines, Library of....Golden, Colo.
Columbia University, Library of....New York, N. Y.
Congress, Library of....Washington, D. C.
Cornell University, Library of....Ithaca, N. Y.
Crombie, James E....Parkhill House, Dyce, Aberdeenshire, Eng.
Dartmouth College Library....Hanover, N. H.
Erdmagnetisches Observatorium und Erdbeben-Station, München, O. 27, Germany
Franklin Institute, The....Philadelphia, Pa.
Fresno Public Library....Fresno, Cal.
Geological Survey, Librarian of....Ottawa, Canada
Geophysical Laboratory....Washington, D. C.
Government Astronomer, Observatory, The....Melbourne, Vic., Aus
Grosvenor Library....Buffalo, N. Y.
Harvard College Observatory....Cambridge, Mass.
Indiana University Library....Bloomington, Ind.
Iowa Geological Survey....Des Moines, Ia.
Iowa State College....Ames, Ia.
John Crerar Library, The....Chicago, Ill.
Johns Hopkins University, Library of....Baltimore, Md.
Lafayette College, Library of....Easton, Pa.
Lick Observatory....Mount Hamilton, Cal.
Los Angeles Public Library....Los Angeles, Cal.
Mechanics-Mercantile Library....57 Post St., San Francisco, Cal.
Meteorological Service, The Director of, Dept. of Marine and Fisheries, Toronto, Ont., Canada
Michigan College of Mines....Houghton, Mich.
Minnesota Historical Society, The....St. Paul, Minn.
Mount Holyoke College, Library of....South Hadley, Mass.
Mount Wilson Solar Observatory, Solar Observatory Office, Pasadena, Cal.
Museum of Comparative Zoology....Cambridge, Mass.
National Geographic Magazine, 16th and M Sts., Washington, D. C.
New York Academy of Sciences, Library, care American Museum of Natural History, New York, N. Y.
New York Public Library, The....New York, N. Y.
Northwestern University, Geological Department....Evanston, Ill.

Norwich Union Fire Insurance Society, Limited, 234-6 Sansome St., San Francisco, Cal.
Observatorio Astronómico..Madrid, Spain
Observatorio del Ebro..................................Tortosa, Tarragona, Spain
Observatorio Meteorológico Central................Tacubaya, D. F., Mexico
Ohio State Library..Columbus, O.
Ohio State University, Library of...................................Columbus, O.
Ohio Wesleyan University, Library of..............................Delaware, O.
Philadelphia, Free Library of, 13th and Locust Sts., Philadelphia, Pa.
Port-of-Spain, Director of Agriculture..............Port-of-Spain, Trinidad
Princeton University, the Library of...............................Princeton, N. J.
St. Ignatius College Library..........2211 Hayes St., San Francisco, Cal.
St. Louis University, Science Library of........Grand Ave. and W. Pine Boulevard, St. Louis, Mo.
Smith College Library...Northampton, Mass.
Smithsonian Institution, Astrophysical Observatory, Washington, D. C.
Sociedad Cientifica "Antonio Alzate"...................................Mexico, Mex.
Spring Valley Water Co., Engineering Dept...........375 Sutter St., San Francisco, Cal.
Sproul Observatory.......................Swarthmore College, Swarthmore, Pa.
State University of Iowa, Library of..................................Iowa City, Ia.
Stevens, B. F., and Brown................4 Trafalgar Square, London, Eng.
Tohoku Imperial University, Library of..............................Sendai, Japan
University of Arizona, Library of..Tucson, Ariz.
University of British Columbia, Library of................Vancouver, B. C.
University of Chicago, General Library of...........................Chicago, Ill.
University of Colorado, Library of......................................Boulder, Colo.
University of Idaho, Library of..Moscow, Ida.
University of Illinois, Library of............University Station, Urbana, Ill.
University of Kansas, Library of.................................Lawrence, Kans.
University of Michigan, General Library of................Ann Arbor, Mich.
University of Minnesota, Library of........................Minneapolis, Minn.
University of Missouri, General Library of....................Columbia, Mo.
University of Nevada, Library of..Reno, Nev.
University of Oregon, Library of...Eugene, Ore.
University of Pennsylvania, Library of..........................Philadelphia, Pa.
University of Rochester, Library of................................Rochester, N. Y.
University of Texas, Library of...Austin, Texas
University of Washington, Library of................................Seattle, Wash.

University of Wisconsin, Library of	Madison, Wis.
U. S. Coast and Geodetic Survey	Washington, D. C.
U. S. Geological Survey, Library of	Washington, D. C.
U. S. Weather Bureau, Library of	Chicago, Ill.
U. S. Weather Bureau, Library of	New Haven, Conn.
U. S. Weather Bureau	Northfield, Vt.
U. S. Weather Bureau, Library of	San Francisco, Cal.
U. S. Weather Bureau, Library of	Washington, D. C.

Members (Life members 22)	306
Subscribers	88
Total	394

ROSSI-FOREL SCALE OF EARTHQUAKE INTENSITIES

I. **Microseismic shock:** recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds; the shock felt by an experienced observer.

II. **Extremely feeble shock:** recorded by several seismographs of different kinds; felt by a small number of persons at rest.

III. **Very feeble shock:** felt by several persons at rest; strong enough for the direction or duration to be appreciable.

IV. **Feeble shock:** felt by persons in motion; disturbances of movable objects, doors, windows; creaking of ceilings.

V. **Shock of moderate intensity:** felt generally by everyone; disturbance of furniture, beds, etc., ringing of swinging bells.

VI. **Fairly strong shock:** general awakening of those asleep; general ringing of house bells; oscillation of chandeliers; stopping of pendulum clocks; visible agitation of trees and shrubs; some startled persons leave their dwellings.

VII. **Strong shock:** overthrow of movable objects; fall of plaster; ringing of church bells; general panic, without damage to buildings.

VIII. **Very Strong shock:** fall of chimneys, cracks in walls of buildings.

IX. **Extremely Strong shock:** partial or total destruction of some buildings.

X. **Shock of extreme intensity:** great disaster, buildings ruined, disturbance of the strata, fissures in the ground, rock-falls from mountains.

INDEX TO VOLUME VIII

PAGE
American Association for the Advancement of Science, gift from.. 90
Arnold, Ralph—Topography and fault system of the region of the San Jacinto earthquake ... 68
Barcelona, Spain, seismological reports received ... 95, 141
Bulletin semestriel de l'observatoire météorologique du séminaire-collège St. Martial, Port-au-Prince, Haiti, for the months July to December, 1916, containing the reports of earthquakes registered at the Port-au-Prince sesimologic station from September 23, 1916, to August 31, 1917, review of, by C. F. Tolman, Jr. ... 41
California earthquakes during 1917, by Andrew H. Palmer ... 1
Cambridge, Mass., seismological reports received ... 95, 141
Coimbra, Portugal, seismological reports received ... 43, 95, 141
Denver, Colorado, seismological reports received ... 43, 95, 141
Earthquake in a mine at Tombstone, Arizona, effects of an, by W. F. Staunton ... 25
Earthquake vibrations, the starting points of, by Harry Fielding Reid ... 79
Earthquake waves, analysis of, by Otto Klotz ... 83
Earthquakes in Southern California, by Homer Hamlin ... 20
Earthquakes in Southern California, the study of, by Harry O. Wood ... 28
Earthquakes in their relation to the Los Angeles aqueduct, by Wm. Mulholland ... 13
Earthquakes, notes and reviews concerning—
    Aguanga, California ... 135
    Baptiste, California ... 136
    Benton, California ... 135
    Cahuilla, California ... 136
    Cairo, Egypt ... 136
    Calexico, California ... 38
    Chile ... 92
    Coachella, California ... 136
    Copiapó, Chile ... 139

Earthquakes, notes and reviews concerning—
  Corfu, Washington ... 138
  Corona, California ... 135
  Cuyamaca Mountains, California ... 136
  Eureka, California ... 91
  Guatemala ... 38
  Guayaquil, Ecuador ... 39
  Hemet, California ... 135
  Imperial Valley, California ... 92, 136
  Italy ... 139
  Kern County, California ... 90
  Jamaica, West Indies ... 139
  Johannesburg, South Africa ... 137
  Los Angeles, California ... 38, 39, 92, 136, 137
  Noria, California ... 136
  Oak Grove, California ... 135
  Olancha, California ... 136
  Panama ... 136
  Pine Bluff, Arkansas ... 137
  Port de France, Martinique, West Indies ... 91
  Porto Rico, West Indies ... 137
  San Jacinto, California ... 91
  Santa Fe, New Mexico ... 92
  Sierra County, California ... 40
  Simi, California ... 135
  Southern California ... 90, 135
  Spokane, Washington ... 40
  Stanford University, California ... 92
  Swatow, China ... 39
  Tahiti ... 139
  Tejon Pass, California ... 91
  Venice, California ... 39, 40, 139
  Virginia ... 90
  Warner Springs, California ... 136
  Washington, D. C. ... 91
  White Bluff, Washington ... 135
  Wister, California ... 136
  Yakima, Washington ... 39

Hamlin, Homer—Earthquakes in Southern California 20
Hazard, D. L.—The relation between seismic and magnetic disturbances 117
Ithaca, New York, seismological reports received 141
Jaggar, T. A. (with Arnold Romberg)—An experiment in teleseismic registration 88
Kilauea, Hawaiian Islands (note) 39
Klotz, Otto—Analysis of earthquake waves 83
La Paz, Bolivia, seismological reports received 43, 95, 141
Lumbier, Manuel M.—La seismologia en Mexico hasta 1917, review, by C. F. Tolman, Jr 93
MacDonald, Bernard—Remarks on the Sonora earthquake—its behavior at Tepic, Sonora, etc 74
Manila, P. I., seismological reports received 43, 95, 141
Masó, Miguel Saderra—Great earthquake and tidal wave in Southern Mindanao, Philippine Islands 125
Mindanao, southern, great earthquake and tidal wave in, by Miguel Saderra Masó 125
Morgan, P. G.—The New Zealand earthquake of August 6, 1917 127
    Eruption of Mount Ngauruhoe, New Zealand, October-November, 1917 129
Mount Ngauruhoe, New Zealand, eruption of, by P. G. Morgan 129
Mulholland, Wm.—Earthquakes in their relation to the Los Angeles aqueduct 13
New Zealand earthquake of August 6, 1917, the, by P. G. Morgan 127
Ottawa, Canada, seismological reports received 43, 95, 141
Palmer, Andrew H.—California earthquakes during 1917 1
Publications received 43, 96, 142
Records, two unique 140
Reid, Harry Fielding—Note on the velocity of long waves and the average depth of the ocean 34
    The starting points of earthquake vibrations 79
Reviews 41, 93
Rolfe, Frank (with A. M. Strong)—The earthquake of April 21, 1918, in the San Jacinto mountains 63
Romberg, Arnold (with T. A. Jaggar)—An experiment in teleseismic registration 88
Rossi-Forel scale 44, 104, 156

San Jacinto earthquake of April 21, 1918, the, by S. D. Townley.... 45
San Jacinto earthquake, topography and fault system of the region of the, by Ralph Arnold 68
San Jacinto earthquake of April 21, 1918, aftershocks of the........ 131
San Jacinto mountains, the earthquake of April 21, 1918, in the, by Frank Rolfe and A. M. Strong.... 63
Seismic and magnetic disturbances, the relation between, by D. L. Hazard 117
Seismológia en Mexico hasta 1917, review of, by C. F. Tolman, Jr. 93
Seismological notes 38, 90, 135
Seismological observations in Osaka, 1916, review of, by C. F. Tolman, Jr. 94
Seismological reports received 43, 95, 141
Seismological Society of America—
  Members of 144
  Minutes of the meeting of Board of Directors, May 4, 1918.... 99
  Officers of Society 143
  Report of Auditing Committee.... 103
  Report of Board of Election.... 100
  Report of Secretary-Treasurer 101
Seismological Station, new 139
Shoddy buildings 140
Sonora earthquake, remarks on the, by Bernard MacDonald.... 74
Staunton, W. F.—Effects of an earthquake in a mine at Tombstone, Arizona 25
Stonyhurst College, England, seismological reports received.... 95
Strong, A. M. (with Frank Rolfe)—The earthquake of April 21, 1918, in the San Jacinto mountains.... 63
Teleseismic registration, an experiment in, by T. A. Jaggar and Arnold Romberg 88
Tolman, C. F., Jr.—Reviews of three publications....41, 93, 94
Townley, S. D.—
  The San Jacinto earthquake of April 21, 1918.... 45
  Minutes of meeting of Board of Directors.... 99
  Report of Secretary-Treasurer 101
Velocity of long waves and the average depth of the ocean, note on the, by Harry Fielding Reid.... 34
Virginia earthquake of April 9, 1918, the, by Thomas L. Watson.. 105

Washington, D. C., seismological reports received................43, 95, 141
Watson, Thomas L.—The Virginia earthquake of April 9, 1918.... 105
Wood, Harry O.—The study of earthquakes in southern California 28
Zi-Ka-Wei, China, seismological reports received..........................43, 95

BRANNER EARTH SCIENCES LIBRARY

300474